1st World Congress on Safety of Transportation

26 – 27 November 1992
Proceedings

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PREFACE

These proceedings contain 70 contributions, presented at "the First World Congress on Safety of Transportation", which took place in Delft on 26 and 27 November 1992. About 200 participants from 21 countries attended the congress, which was held in the context of the 150th anniversary of the Delft University of Technology.

The Aim of the Congress was twofold:
- the advancement of transportation safety, by the exchange of information concerning the experiences gained from operational practices within different modes of transportation
- to discuss the possibility of and recommendations for a European organization in which the different transport modes and countries can learn from each other.

We may look back at a very successful congress. The Transportation Safety Councils of the USA, Canada, Sweden and the Netherlands exchanged their views and issued a declaration to cooperate in the near future. During the congress the National Transport Safety Board brought up the idea of a series of international transportation safety congresses, thus declaring this congress the first in that series. In France, the idea of a National Transportation Safety Council has arisen as well shortly after our congress.

During the congress, the need to promote the exchange of transportation safety experiences between modes and the exchanges of information between researchers on an individual level generated a declaration among seven research institutes in The Netherlands. The research institutes decided to cooperate on the research of underlying, generic scientific issues and will draw up a portfolio of research projects. The declaration is included in the proceedings.

Shortly after the congress a number of serious transportation accidents occurred in The Netherlands. The transfer of information to the public about the fact finding and investigation into the causes of these tragedies demonstrated that we are faced with a number of unsolved problems. The independent investigator of such an accident who wants to inform the public finds himself in a vulnerable position, because the difference between the question of blame and the question of accident causation is not yet clearly discernable for everybody. On the other hand, such an investigator may play a, up to this moment unknown, role. The way the public responded to the accidents demonstrated that he may serve as a Public Counsellor, who is able to receive confidential information from the public, which otherwise might be held back. Accident investigation by an independent researcher may gain the confidence of the public that the investigation and the findings are not submitted to conflicting interests.
During and after the congress it therefore became clear to me what the aim of this congress was: to show society as a whole and safety experts in particular what we are doing; to reduce the un-safety of our industrialized world to an absolute minimum. We have the profound duty towards the casualties and their relatives and friends to deal as carefully as possible with the experiences we gained from accidents, to improve the safety of the systems in the future.

Within that aspiration it is appropriate to:
- include in this learning process the experiences from the past and from other countries
- establish comparative studies between the various safety management systems of the different modes of transportation
- redesign transportation systems for enhanced safety
- develop scientific methods to analyze the expected un-safety of transportation systems and their infrastructure
- establish a small organization to repeat our congress at regular intervals, each time in a different country
- strive for research councils and institutes which are independent of the parties involved in accidents
- strive for national and international networks between these councils and institutes

We are very grateful to the Von Baumhauer Fund, which enables us to have these Proceedings printed.

Finally, I want to express my gratitude towards all participants, in particular the authors, without whom there would have been no successful congress and who made it possible to continue on our way to a safer world.

Prof. J.L. de Kroes
Chairman of the Congress
DECLARATION

Issued at the

1ST WORLD CONGRESS ON SAFETY OF TRANSPORTATION

27 - 27 November 1992

Delft University of Technology

The Netherlands

Considering the increasing scale, complexity and interwovenness of modern transportation systems, the Dutch research institutes for transportation conclude that the underlying, scientific issues that may prove to be generic to questions of transportation safety warrant a research programme in its own right.

They unite to this purpose on the basis of knowledge available to them, where possible in an international setting and will formulate and execute a portfolio of research projects to this end.

Initiative by

National Aerospace Laboratory
TNO - Institute for Perception
TNO - Road Vehicle Research Institute
Institute for Road Safety Research
Delft University of Technology
European Railroad Research Institute ERRI
Maritime Research Institute Nederland, MARIN

Delft, 27 November 1992
EXPLANATION

Paying tribute to

The World Congress of Science of Transportation

20 - 24 November 1952

Delegates of all countries

The photographs
Albert Gilles von Baumhauer

Albert Gilles von Baumhauer, born October 10, 1891, was a mechanical engineer who had studied at the Delft University of Technology and similar institutes at Göttingen and Zurich. While still a student he showed great interest in aviation, although in those days it was not yet a subject for any serious scientific study.

After completing his studies he was employed by Dutch aircraft factories and later by the Government in the Rijksstudiedienst voor de Luchtvaart (Government Aeronautical Research Institute) from 1921 to 1937, of which he became assistant director. From 1937 he was with the Dutch Civil Aeronautics Administration, his duties including the inspection of new aircraft types and the investigation of accidents.

On March 18, 1939 at the age of 47, he was killed in an accident which occurred in the USA during a trial flight with the prototype of the Boeing Stratoliner; Mr. P. Guillonard, assistant manager of KLM, died in the same accident.

Von Baumhauer had an exceptionally versatile mind and at an early age he had a clear insight into the technical problems of aviation. His interests and activities were concerned with designing, stressing, construction, research and flying itself (he was a pilot of both powered aeroplanes and gliders). In addition he did a great deal to propagate aviation and contributed articles to learned professional journals and to newspapers. He was intensely occupied with the problem of safety in aviation and he felt that one of his most important tasks was to find the cause of aeroplane accidents and the means for preventing them.

In addition to his capacity for exact scientific thinking, Von Baumhauer was gifted with a sound imagination and progressive ideas. While at the University in 1910 he was already carrying out measurements of lift and drag of various wings sections. At the time when thin, or at best slightly curved lifting surfaces were in general use, he was already firmly convinced of the advantage of a thick cambered wing. His many reports on research work carried out by him, dealt among others with drag, aircraft control, ice-accretion, flow-investigation and unstable vibration of wings.

Early in his career, Von Baumhauer discovered the nature of wing-flutter when investigating the failure of an aeroplane in flight of which the pilot reported heavy vibrations. Von Baumhauer gained the major part of his international fame through his development work on helicopters, carried out in the years 1924-1930. He also possessed pedagogic and didactic gifts, and in particular he was able to present problems in a simple way. He was the moving spirit in organizing a course in aircraft construction forming a part of the construction given at Secondary Technical Schools.

With an almost prophetic eye he foresaw several developments. In his writings he described the principles for a convertiplane and mentioned the method of tip jet propulsion.

There is no doubt that, had he been spared, his exceptional talents and foresight would have been of even more service to the world.
Opening by prof. P.A. Schenck,
Rector Magnificus Delft University of Technology

Mr. Chairman, Ladies and Gentlemen,

There are many reasons to feel honoured and pleased to welcome you here today at Delft University of Technology.

First, and I hope that you will understand that I mention this in the first place, 1992 is the year during which our University celebrates its 150th anniversary. On January 8th, 1842, King William II signed the official decree establishing an 'Academy for the Training of Civil Engineers'. From this Academy evolved the present Delft University of Technology when it got the right to award doctorates in 1903. This happened since that time about 2100 times; 84 honorary doctorates have been awarded.

The 150th anniversary was commemorated on January 22nd of this year in an official academic ceremony in the presence of Her Majesty the Queen. It goes without saying that in an early stage of preparation it was decided to celebrate this 150th anniversary not only by this official session. Quite a few number of festivities have been organised, many of them as sports- and festive happenings in which techniques played often a characteristic role, e.g. in a race in self-built concrete canoes. During three consecutive days, many aspects of technique and its applications were demonstrated to the public at large. These days, and the 'Jazz boulevard' attracted some 30,000 visitors.

A university, however, is an educational and scientific institution. We therefore planned right from the beginning a series of scientific congresses covering as much as possible the fields in which our University plays an active role, all be it in such a way that not specifically faculties participated in isolation. Modern research requires very often contributions from several different faculties. This also became clear in our congresses. Many proposals have been put forward and a scientific selection committee ultimately accepted some 30 of those. Most of those had an international character; some of them were very large ones with up to 800 participants, others small ones for the specialists in a certain field. In total some 6000 participants attended these conferences, about half of them from outside the University, thousands of participants from foreign countries.

A few congresses had a very general character, related to technology: the official 'Lustrum Congress' 'Tracing Technology', organised last January aimed at participants from all faculties. It put technology in the much wider context of history, art, philosophy and even the future. A second general congress - offered to the University by the Royal Institute of Engineers - treated engineering education at a University level and one could say the congress starting today is a third in this row of special congresses.

This congress on 'Safety of Transportation' closes the cycle of Lustrumcongresses in this year; its general aspect and the relation of technology and society is very well in tune with the first congress 'Tracing Technology'. It is also well planned to have this congress in Delft: in the field of transportation many of our faculties play an important role: those of Civil Engineering, Mechanical Engineering, Ship Building, Aerospace Engineering; Electrical Engineering, to mention the most important ones.
Recently a cooperative institute covering the activities in transportation research in the various faculties has been established officially: the institute DITRAIL: the 'Delft Institute of Transport, Infrastructure and Logistics'.

In this context it is most interesting that our University also accommodates a faculty of Philosophy and Humanities, in which a chair in safety Aspect of technology has been established already many years ago. During this congress both technical and social/psychological aspects come together and as such it fits quite well in the present situation at Delft University of Technology. Not only pure technical aspects are considered, but also the relation of technique to human behaviour. It stands, however, also in a long tradition of this University: as far back as 1890 the Delft University stood in the forefront when laws on labour and safety were introduced. It brought forward a great number of specialists in that field; the name of Pekelharing, a professor at this university in that period is closely linked to this Delft School on Labour and Safety.

This time too, Delft University of Technology may play a stimulating role: this First World Congress on Safety of Transportation could become the start of a period during which the challenge of better integration of Transport and Safety will be taken.

This is the start of two interesting days, concerning important subjects of discussion. This importance of the congress is underlined by your presence, Mr. van Vollenhoven. Safety in transportation for a long time has had your great interest and we feel honoured that you express this interest not only by attending part of this congress but also by presenting a lecture. This congress is an international congress. This is self-evident since transport and safety in transportation need international consideration. One could say that our present-day society is strongly based on it.

I congratulate the organising and scientific committee on their success in putting together a most interesting programme, bringing to Delft experts in various fields. I do wish you two very interesting days of lectures and discussions and I do hope that also the informal discussions during coffee breaks and luncheons will prove to be stimulating.

Delft University of technology welcomes you on its premises and I wish you a good and fruitful stay at the University and a few nice days in this old town of Delft.
PLENARY OPENING SESSION - I
Opening-speech by Mr. Pieter van Vollenhoven, chairman of the Dutch Road Safety Council and chairman of the Dutch Railway Accidents Council.

Transport Safety Congress, 26 November 1992, Delft

"Accident investigation and international cooperation"

Mr Chairman, ladies and gentleman,

First I would like to congratulate Delft University of Technology on its 150th anniversary. I greatly value the fact that in this special year the University has once again seen fit to put the spotlight on transport safety. In so doing, it is showing both courage and tenacity for it is a subject in which, I can safely say, very few people have shown any interest to date. In all the years that I have been involved in transport safety, I have never known this university hesitate in bringing this topic to the fore. In its 150 years it has clearly acquired the wisdom and insight which we should all be striving for, and this brings me back to the two objectives of this congress:
Objectives

firstly, to promote transport safety through the exchange of experience, and secondly, to explore the possibility of setting up an international organisation in this sphere.

First, I should like to express my support for these aims. I shall explain later on why I think they are important. If it were up to me to decide how these aims were to be implemented, I would emphasise the value and necessity of independent investigations into the causes of accidents in general and accidents in different types of transport in particular. I am also firmly in favour of the establishment of an international association comprising all the independent and permanent investigation committees and councils active in the fields of aviation, road and rail transport, and shipping. Such an association would, I am certain, play a very important role in the exchange of experience and information in the field of transport safety.
A sectoral approach to safety

Let me begin with a brief explanation of why I support the objectives of this congress. In the past 26 years*, during which time I have been involved in various aspects of safety in aviation and road and rail transport, I have regrettably come to the conclusion that there is often a very negative attitude towards the concept of cooperation and the exchange of experience in this area. A sectoral approach to safety in general and the fragmentation of government responsibility have compounded the problem. Safety - a subject which most people are genuinely concerned about - has traditionally been the responsibility of government. As a result, safety aspects became the concern of whichever department was responsible for a particular sector. Each sector developed separately its own safety regulations and its own

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* Wing commander (pilot) in the Royal Netherlands Air Force Reserve.

1966   Legal Department of the Staff of the Commander in Chief of the Air Force
1966   Air Defence Command, Zeist, investigation of aircraft accidents
1967   Pilot training (Military Pilot Licence, Gilzerijen)
1968   Reserve Officer (pilot) 300 squadron, Deelen air base
1977   Chairman of the Road Safety Council
1984   Chairman of the Railway Accidents Council
1990   Adviser to EC-commissioner Van Miert on the establishment of a European Council for Transport Safety
system of supervision and enforcement, each department acting independently of the others. In fact, one might say that each sector reinvented the wheel of safety for itself. In short, departmental fragmentation is a major obstacle to the exchange of experience.

Tendency toward cooperation and harmonisation

The fact that a change for the better is now discernable in the Netherlands and elsewhere can, in my view, be attributed to three trends. First, transport flows are increasingly being viewed from an international perspective, accompanied by a growing awareness of the integral nature of the transport chain as a whole. As the various branches of transport become successively more intertwined, closer coordination of policy is called for and regulations have to be made as uniform as possible.

Secondly, cuts in government expenditure are forcing organisations and agencies to work together, in the field of safety or elsewhere.

Finally, people have started to realise that society may one day have to pay the price for allowing so many different regimes for the
enforcement of safety regulations to exist side by side.

Harmonisation in this sphere would automatically entail a greater exchange of knowledge. As for supervision, it is very odd that a foreign ship in a Dutch port can be placed under embargo for safety reasons under the terms of international agreements, but that under the Chicago Convention the safety of aircraft is a matter for the country of registration.

The path towards cooperation and harmonisation is long and hard. It is only logical therefore, much as we may regret it, that even now in 1992 the objectives of this congress have had to be presented in such a tentative way.

Indeed, the letter I received with the first call for papers referred merely to "raising for discussion" the topic of new developments and the exchange of experience. But in my opinion speed is essential for several reasons.
Safety and the environment

As far as the environment is concerned, national and international awareness of environmental issues is now fortunately growing, and rightly so. I am firmly convinced, however, that many of these problems cannot be tackled effectively unless, at the same time, we give safety a higher priority. Many of the environmental disasters that have occurred to date can be attributed to the repeated failure to observe safety regulations. I only have to remind you of the consequences of the incidents involving the Exxon Valdez in Alaska, the Amoco Cadiz in Brittany, or in another field, Chernobyl.

Meanwhile, the world is changing. New countries are emerging, and the economic outlook, for all of us, is less than rosy. If we want to secure a place for safety on the agenda, to safeguard it and, at the same time, give it a higher profile, then it is even more essential that the objectives of this congress are achieved.
Independent investigations into the causes of accidents

If any progress is to be made, I would suggest, in implementing the objectives of this congress, that an approach be adopted, to which everyone in fact subscribes, namely that, whenever a major disaster occurs, an independent investigation into the cause of the accident should be held immediately. Few people realise that the independence and quality of the committees that conduct such investigations are sometimes highly doubtful. Despite the terrible disaster which is still fresh in all our memories, major disasters do not occur very frequently. Permanent independent committees of investigation are therefore rare and are regarded as superfluous. It is even claimed that their members would run the risk of becoming rusty through lack of work. In most countries such committees are therefore appointed on an ad hoc basis and comprise persons who work in the sector concerned, perhaps in the field of regulations or safety inspection. The committee is usually headed by an independent expert, often drawn from the judiciary.
For a long time the only exception to these committees, whose impartiality is questionable, was the National Transportation Safety Board in the United States, which was set up in 1967. The NTSB is responsible for investigating transport accidents of every kind, from aviation, shipping, and road or rail transport to pipelines; including investigating all transport accidents involving hazardous materials. The main arguments in favour of setting up this organisation were to ensure an independent opinion and to bring the various sectors of transport under one roof. The need for independence was emphasised by Congress because of the major interests which were often at stake. Accident investigations which seek to learn from the errors made and increase safety in the future at times do not square with economic interests. By bringing together all types of transport under one roof, Congress hoped to focus greater attention on safety than was possible with each sector acting separately.

The lessons to be learned from America

What can we learn from NTSB's experiences? First, the impartiality of an investigation is never questioned so that its findings carry far greater weight.
Second, experience has shown that the same method of investigation can be used for each and every accident, whatever its nature. This may well prompt us to consider whether these methods should be extended to accidents outside the transport sector. Indeed there are some countries, such as Sweden, where a much broader system exists and all accidents are investigated by one and the same organisation. For the time being, however, it is probably better to stick to what we know best and confine ourselves primarily to the transport sector. Third, considerable value is attached to the exchange of data between the various sectors. Fourth, the quality of accident reports has improved thanks to cooperation, and fifth, permanent boards of investigation are able to follow up their recommendations so that they are not simply filed away and ignored. This is the only way to ensure that safety does indeed improve. Another advantage of a permanent organisation is the scope for carrying out studies and producing recommendations without a specific accident having taken place. This has a greater preventive effect.
Finally, it seems to me that if the United States had the same choice to make again, it would opt once again for a joint board of investigation rather than separate bodies for each branch of transport, as is the case in the Netherlands, for instance. Of course you could argue that the NTSB was set up in another era and that no-one is about to admit that they got it wrong. What, in my view, proves that the NTSB has lived up to expectations, however, is the fact that just a couple of years ago - in 1990 - the Canadian Transportation Safety Board was set up on exactly the same principle.

The path ahead

If you consider these experiences and view them in relation to the objectives of this congress, it should be all too apparent what path we should take in the future. If we wish to promote the exchange of experience in the field of transport safety, it seems to me only logical to set up a international association of independent transport investigation boards, even if they work in one sector only. Initially, comparatively few countries would be involved. The ultimate aim, of course, would be to incorporate as many countries as possible.
The number of members would therefore rise as the importance accorded to independent accident investigations grew and more permanent bodies were set up.

Some time ago I advised the EC Transport Commissioner, Mr Van Miert, to establish a European Transport Safety Board to draw up recommendations on road safety and bring together the independent boards of investigation for aviation, shipping, rail and road accidents in the EC member states. The idea failed to get off the ground. It turned out that the EC was not empowered to appoint a permanent independent advisory body of this kind. Even if it had been, I am not sure that the transport ministers at the time would have liked the idea of having an independent adviser supervising them in this area. Moreover, I discovered that very few independent boards of investigation working in the field of transport safety in fact existed in the EC, so it was difficult to bring them together on short notice. Fortunately my advice was not in vain, however. First, it has prompted a new initiative by the German DVR, the British PACTS and the Dutch Road Safety Council, who together propose to establish a European Transport Safety Group. Professor Mackay will tell you more about this shortly.
Secondly, it also provided me with a basis for helping to establish an international association of independent transport investigation boards.

Establishment of an international association

Bearing in mind the objectives of this congress, I would like to stress once again the desirability of an international association of independent accident investigation boards working in the transport sphere. Accordingly, it gives me great pleasure to announce that the National Transportation Safety Board of America, the Canadian Transportation Safety Board, the Swedish Board of Accident Investigation and two Dutch councils, the Road Safety Council and the Railway Accidents Council, have expressed their willingness to initiate discussions establishing such an association.

In my view, the values of such an association are:

1. adequate independent investigations contribute enormously to safety and the protection of the environment. Most environmental disasters can be attributed to shortcomings in safety policy and regulations;
2. impartiality is required because of the many conflicting interests at stake in in-depth investigations of this kind, including the interests of government and industry, safety, profit margins and so on;
3. although the need for an investigation is generally not in doubt, the way in which it is conducted often raises numerous questions;
4. many countries have no permanent board of investigation, although ad hoc committees may be created;
5. the exchange of recommendations is not yet common practice.

The objectives of such an association could include:

1. to improve the standard of independent investigations into the causes of accidents;
2. to exchange information through databases;
3. to monitor [and evaluate] the follow-up of safety recommendations.
The membership of other independent national boards, committees or institutes will be welcomed to make this a truly worldwide body. Once such an association is formed, details regarding its secretariat, chairmanship, meetings, working methods, and its relationship to other international bodies concerned with safety in the various branches of transport will be expeditiously finalised.

Once formed, the International Association of Transport Accident Investigation Boards, or IATAIB, will primarily be a forum for cooperation between national transport accident investigation boards.

Conclusion

Finally, there is also the question of whether a Dutch Transport Safety Board should be set up or whether the five existing Boards should continue to operate separately.

In the light of experience abroad, I would opt for the first alternative. I mentioned earlier that in the Netherlands at least, we are witnessing a welcome trend towards cooperation and the pooling of resources. One example is the willingness of the Dutch Ministry of Transport to consider such a suggestion. Such a development would have been
unthinkable in the past because of the fragmentation of the transport sector.

Well, I have come to the end of my address. I would like to conclude by once again expressing my sincere gratitude towards Delft University of Technology and in particular to Professor De Kroes, who were again prepared to organise this congress. I am convinced that it will definitely lead to positive results.
"The NTSB's Approach To Improving Safety"

Presented By

HON. CARL W. VOGT
Chairman
U.S. National Transportation Safety Board

At the

SAFETY OF TRANSPORTATION CONGRESS

November 26, 1992
Delft University of Technology, The Netherlands
I AM VERY PLEASED TO BE HERE THIS MORNING BEFORE SUCH DISTINGUISHED INTERNATIONAL GROUP. AS CHAIRMAN OF THE U.S. NATIONAL TRANSPORTATION SAFETY BOARD, AND REPRESENTING FOUR OTHER MEMBERS WHO SEND THEIR GREETINGS, I WELCOME THE OPPORTUNITY THIS MEETING OFFERS FOR A WORTHWHILE EXCHANGE OF IDEAS.

IT IS A SPECIAL HONOR FOR ME, AS THE NEW HEAD OF THE SAFETY BOARD, TO BE HERE AT THIS TIME FOR THIS YEAR MARKS OUR AGENCY'S 25TH ANNIVERSARY AS ONE OF THE FINEST TRANSPORTATION INVESTIGATIVE AGENCIES IN THE WORLD. IN THE LAST 25 YEARS, THE SAFETY BOARD HAS SIGNIFICANTLY RAISED THE LEVEL OF TRANSPORTATION SAFETY IN THE UNITED STATES. IT IS DONE SO BY IMPROVING AND STANDARDIZING THE INVESTIGATIVE PROCESS IN ALL AREAS OF TRANSPORTATION.

OVER THE YEARS, OUR CONGRESS HAS RECOGNIZED THE VALUE OF THE AGENCY, FIRST ESTABLISHING ITS PRIMACY OVER INVESTIGATIONS CONDUCTED BY OTHER FEDERAL AGENCIES AND THEN BROADENING ITS INTER-MODAL JURISDICTION. A CRITICAL ELEMENT TO THE SAFETY BOARD'S SUCCESS IS A CONGRESSIONAL MANDATE THAT CALLS FOR MAKING CONCLUSIONS AND RECOMMENDATIONS THAT MAY BE CRITICAL OF OR ADVERSE TO THE TRANSPORTATION MODAL AGENCIES OR THEIR OFFICIALS.

SAID THE CONGRESS; "NO FEDERAL AGENCY CAN PROPERLY PERFORM SUCH FUNCTIONS UNLESS IT IS TOTALLY SEPARATE AND INDEPENDENT FROM ANY OTHER... AGENCY OF THE UNITED STATES."

I HAVE BEEN DEEPLY IMPRESSED BY THE INTEGRITY OF THE SAFETY BOARD AND THE SERIOUSNESS OF ITS MISSION. MY GOAL IS TO FULLY SUPPORT AND ADVANCE THAT MISSION AND, WHERE POSSIBLE, FOSTER RELATIONSHIPS IN THE U.S. AND ABROAD TO FURTHER THAT GOAL. ONE WAY TO DO THIS IS THROUGH CLOSER TIES WITH NATIONAL ACCIDENT INVESTIGATION AGENCIES.

THE SAFETY BOARD IS A SMALL AGENCY HEADED BY FIVE MEMBERS NOMINATED BY THE PRESIDENT AND CONFIRMED BY THE SENATE FOR FIVE-YEAR TERMS. ONE MEMBER IS DESIGNATED TO SERVE AS CHAIRMAN AND ONE AS VICE-CHAIRMAN FOR TWO-YEAR TERMS. OUR SPECIFIC MISSION HAS BEEN TO DETERMINE THE "PROBABLE CAUSE" OF ACCIDENTS AND DEVELOP RECOMMENDATIONS TO IMPROVE TRANSPORTATION SAFETY. WE OPERATE OUT OF OUR HEADQUARTERS IN WASHINGTON, D.C. AND REGIONAL OFFICES THROUGHOUT THE COUNTRY.

OUR SCOPE IS MULTI-MODAL AND COVERS ALL U.S. CIVIL AVIATION ACCIDENTS: SELECTED HIGHWAY ACCIDENTS, RAILROAD AND PIPELINE MISCHAPS INVOLVING A FATALITY OR SUBSTANTIAL PROPERTY DAMAGE; AND MAJOR MARINE ACCIDENTS OR ANY INVOLVING A PUBLIC AND A NON-PUBLIC VESSEL.

I WOULD LIKE TO SHARE WITH YOU SOME OF THE TYPES OF ACCIDENTS THE SAFETY BOARD HAS INVESTIGATED OVER THE YEARS IN ALL MODES OF TRANSPORTATION.

(SLIDE A) WE ARE, OF COURSE, BEST KNOWN FOR OUR AVIATION ACCIDENT INVESTIGATIONS. THIS IS THE SCENE OF THE TAKE-OFF CRASH OF A NORTHWEST AIRLINES MD-80 AT DETROIT, MICHIGAN MORE THAN FIVE YEARS AGO. OF THE 155 PERSONS ON BOARD THE AIRCRAFT, ALL BUT ONE - A FOUR YEAR OLD GIRL - DIED. WE DETERMINED THE ACCIDENT OCCURRED WHEN THE CREW FAILED TO USE THE CHECKLIST TO ENSURE THAT THE AIRCRAFT'S SLATS AND FLAPS WERE PROPERLY CONFIGURED FOR TAKE-OFF.
(SLIDE B) THIS USAIR B-737 CAME TO REST AGAINST A VACANT LOS ANGELES AIRPORT BUILDING AFTER LANDING AND COLLIDING ON THE RUNWAY WITH A SKYWEST AIRLINES COMMUTER PLANE. THIRTY-FIVE PEOPLE WERE KILLED IN THE ACCIDENT, WHICH OCCURRED AS THE SKYWEST PLANE WAS SITTING ON THE RUNWAY AWAITING ITS TAKE-OFF CLEARANCE AND THE USAIR PLANE WAS CLEARED TO LAND ON THAT SAME RUNWAY. IN THAT ACCIDENT WE DETERMINED THE LOS ANGELES TOWER USED IMPROPER CONTROL PROCEDURES AND THE FEDERAL AVIATION ADMINISTRATION FAILED TO PROVIDE ADEQUATE DIRECTION TO AND OVERSIGHT OF ITS FACILITY MANAGERS.

(SLIDE C) MORE RECENTLY THE SAFETY BOARD INVESTIGATED THE CRASH OF THIS CONTINENTAL EXPRESS EMB-120 IN TEXAS, WHICH RESULTED IN THE DEATHS OF ALL 14 PERSONS ABOARD THE AIRCRAFT. THE PLANE LITERALLY FELL FROM THE SKY WHEN IT EXPERIENCED A STRUCTURAL BREAK-UP AT AN ALTITUDE OF 11,000 FEET. WE DETERMINED THE BREAK-UP WAS CAUSED BY THE FAILURE OF THE AIRLINES MAINTENANCE PERSONNEL AND INSPECTORS TO FOLLOW APPROVED PROCEDURES WHEN WORK WAS PERFORMED TO REPLACE THE AIRCRAFT'S DE-ICE BOOT THE EVENING BEFORE THE ACCIDENT. THE WORK WAS BEGUN BUT NOT FINISHED, AND AS A CONSEQUENCE 47 SCREWS WERE REMOVED, BUT NOT REPLACED, ON THE PLANE'S HORIZONTAL STABILIZER.

(SLIDE D) IN THE MARINE MODE, OUR INVESTIGATION OF A FIRE AND EXPLOSION ABOARD THE TANKSHIP JUPITER AT A MOORING FACILITY IN MICHIGAN RESULTED FROM A GASOLINE DISCHARGE HOSE THAT RUPTURED AND SPILLED FUEL WHEN A PASSING VESSEL CREATED A WAKE. ONE CREWMAN DROWNED WHEN HE JUMPED FROM THE exploding SHIP, AND DAMAGE TO THE MOORING FACILITY AND THE TANKSHIP TOTALLED MORE THAN NINE MILLION DOLLARS.

(SLIDE E) ONE PERSON WAS KILLED AND NINE OTHERS INJURED WHEN A NATURAL GAS EXPLOSION AND FIRE DESTROYED TWO HOUSES IN ALLENTOWN, PENNSYLVANIA. IN THIS ACCIDENT WE DETERMINED THAT WATER LEAKING FROM A CRACKED WATER MAIN HAD ERODED THE SOIL BENEATH THE GAS MAIN, WHICH SUBSEQUENTLY CRACKED AND RELEASED NATURAL GAS THAT MIGRATED INTO THE BASEMENT OF ONE OF THE HOUSES.

(SLIDE F) WHEN A TEMPORARY BRIDGE IN OHIO COLLAPSED, TWO PERSONS WHO WERE TRAVELLING OVER THE BRIDGE AT THE TIME WERE KILLED. WE FOUND THAT TEMPORARY BRIDGES DO NOT HAVE TO BE BUILT TO THE SAME MINIMUM LOADING SPECIFICATIONS OF PERMANENT BRIDGES - AND THAT CAUSED THIS ACCIDENT.

(SLIDE G) THREE CREWMEMBERS DIED WHEN TWO TRAINS COLLIDED IN GEORGIA- A COLLISION THAT OCCURRED WHEN THE ENGINEER OF ONE OF THE TRAINS FAILED TO STOP HIS TRAIN BECAUSE HE WAS EITHER ASLEEP, DISTRACTED OR INATTENTIVE. AT THE TIME OF THE ACCIDENT, THE ENGINEER HAD BEEN AWAKE FOR 17 HOURS. THIS AND OTHER NUMEROUS ACCIDENTS HAS INCREASED THE SAFETY BOARD'S INTEREST IN AND CALL FOR MORE RESEARCH ON THE EFFECTS OF FATIGUE IN TRANSPORTATION ACCIDENTS.

OUR SCOPE ALSO INCLUDES RELEASES OF HAZARDOUS MATERIALS IN ANY FORM OF TRANSPORTATION, AND TRANSPORTATION PROBLEMS INVOLVING PROBLEMS OF A REOCCURRING NATURE IN THE LATTER CASE THAT USUALLY INVOLVES THE CONDUCT OF SPECIAL SAFETY STUDIES. WE HAVE CONDUCTED STUDIES IN A VARIETY OF AREAS, FROM AIR TRAFFIC CONTROL, LOCOMOTIVE FUEL TANK CRASHWORTHINESS AND SCHOOL BUS DESIGN TO HEAVY TRUCK BRAKES, RECREATIONAL BOATING AND AUTOMOBILE LAP/SHOULDER BELTS.
Earlier this year the Safety Board adopted a study on heavy truck brakes, one of the accidents we investigated in the course of that study occurred in Kent, Washington. One person was killed and eight others injured - including the truck driver - when the loaded dump truck and trailer failed to stop at an intersection, we determined that the accident was caused by a lack of braking capabilities on the part of the truck - a condition that we traced to the chronically deficient carrier maintenance program.

The Safety Board also has three additional major activities. We maintain the official civil aviation accident database for the U.S. and annually release a statistical summary of aviation accidents for the previous year, we review appeals from airmen and merchant seamen whose certificates have been revoked or suspended by other governmental entities, and we lead U.S. teams on foreign airline accident investigations to assist foreign authorities under International Civil Aviation Organization (ICAO) provisions - such as our assistance in the tragic Et Al crash investigation in Amsterdam last month.

Our investigations are built around a multi-disciplinary "Go-Team" concept. This is a rotating group of Safety Board investigators on 24-hour call who possess a wide range of special investigative skills. In aviation, such a Go Team typically includes an investigator-in-charge and experts trained in witness interviews, air traffic control systems, power plant and aircraft operations. One of the five board members may also accompany the Go Team.

The Go Team is similar in the case of a railroad accident but the "specialties" usually consist of track engineers, locomotive and signal specialists and operations experts. We have specially trained experts when investigating accidents in the maritime, pipeline and highway fields.

Some specialists are "intermodal," such as meteorologists, metallurgists, human factors and hazardous materials experts. Their expertise is applicable to every transportation mode. I will defer discussing the specifics of our investigative process itself for this will be dealt with in depth by our managing director at a session tomorrow.

We measure our effectiveness in recommendations and their adoption. The Safety Board issues a recommendation as soon as a problem is identified, without necessarily waiting until an investigation is completed and the probable cause of the accident is determined. Each recommendation issued by the Safety Board designates the person or party expected to take action, describes the action we recommend, and clearly states the safety need to be satisfied. Although our recommendations are not mandatory, to emphasize their importance Congress requires the U.S. Department of Transportation to respond to each recommendation within 90 days.

To date, we've issued more than 9,000 recommendations to various government entities, private companies, trade associations and others. The average acceptance rate of all our recommendations in the various transportation modes is above 80 percent, and this makes us quite proud.
WE FIND IN THE U.S. THAT HAVING ALL MODES OF TRANSPORTATION IN ONE ACCIDENT INVESTIGATION AGENCY HAS CERTAIN ADVANTAGES. THE BENEFITS ARE IN THE ECONOMY OF OPERATION. THE TRANSFERABILITY OF SAFETY LESSONS FROM ONE TRANSPORTATION MODE TO ANOTHER, AND THE DEVELOPMENT OF IMPROVED INVESTIGATIVE TECHNIQUES IN MORE THAN ONE TRANSPORTATION FIELD.

OUR TECHNICAL LABORATORIES. OUR LAB SPECIALISTS HAVE BEEN ABLE TO READ OUT FLIGHT RECORDERS ON TRAINS AND MARINE RECORDERS ON SHIPS. OUR METALLURGISTS ANALYZE FATIGUE SITUATIONS IN A WING-SPAR AS COMPETENTLY AS A FATIGUE CRACK IN A TRAIN RAIL. A COMPUTERIZED MODEL OF A TRUCK ROLLOVER IS AS READIPLY AVAILABLE AS AN AIRPLANE CRASH SIMULATION.

THE FINAL RESULTS OF OUR INVESTIGATIONS ARE ENHANCED BY THE CLOSE WORKING RELATIONSHIPS AMONG OUR VARIOUS INVESTIGATORS. THIS HAS RESULTED IN INFORMATION BEING ACCESSIBLE AND EASY TO OBTAIN. HERE ARE SOME EXAMPLES:

WE HAVE BEEN ABLE TO RECOMMEND IMPORTANT CHANGES IN THE USE OF RADIOS IN RAILROAD OPERATIONS FROM WHAT OUR INVESTIGATORS HAVE LEARNED ABOUT COMMUNICATIONS IN AVIATION OPERATIONS. OUR RECOMMENDED IMPROVEMENTS IN AIRCRAFT COCKPIT RESOURCE MANAGEMENT ARE NOW BEING ADAPTED TO SHIPS' BRIDGE RESOURCE MANAGEMENT. OUR WORK ON FRICTION IN HIGHWAY ACCIDENTS HAS GIVEN US BETTER INSIGHT INTO AIRPORT RUNWAY SKIDDING AND HYDRO-PLANING PROBLEMS. AND OUR INVESTIGATIONS INTO ALCOHOL-RELATED HIGHWAY ACCIDENTS HAVE HELPED US FRAME RECOMMENDATIONS FOR CORRECTING ALCOHOL AND DRUG ABUSE IN RAILROAD, AVIATION AND MARINE OPERATIONS.

IN PASSENGER SURVIVAL, OUR INVESTIGATIONS HAVE FOUND THAT IMPROVEMENTS IN CRASHWORTHINESS AND FIRE PREVENTION IN AVIATION HAVE APPLICATION TO RAILROAD CARS, BUSES AND OTHER PASSENGER VEHICLES. MEANWHILE, THE SAFETY BOARD'S KNOWLEDGE HAS PLAYED AN INSTRUMENTAL ROLE IN THE DEVELOPMENT OF A CHILD SAFETY SEAT ACCEPTABLE FOR BOTH AVIATION AND HIGHWAY VEHICLES.

IN HAZARDOUS MATERIALS, PROBLEMS WE HAVE FOUND IN THE LABELING, MARKING AND PLACARDING IN ONE FORM OF TRANSPORTATION ALSO HAVE BEEN DETECTED AND CORRECTED IN OTHER MODES. WE HAVE BEEN ABLE TO ALERT INDUSTRIES TO STATIC ELECTRIC DANGERS OUR INVESTIGATORS HAVE FOUND IN CERTAIN LOADING PRACTICES OF HAZ-MAT MATERIALS. IN ADDITION THE SAFETY BOARD'S KNOWLEDGE GAINED FROM HAZ-MAT INVESTIGATIONS HAS BROUGHT ABOUT BETTER TECHNIQUES, GREATER UNIFORMITY AND SPEED IN HANDLING EMERGENCIES.

MUCH OF THE SUCCESS THE BOARD ENJOYS IN ENHANCING SAFETY COMES THROUGH OUR RELATIONSHIPS WITH THE TRANSPORTATION-ORIENTED CONGRESSIONAL COMMITTEES, GOVERNMENT AGENCIES AND TRADE ASSOCIATIONS. WE HAVE A REPUTATION FOR BEING ACCESSIBLE, FORTHRIGHT AND TECHNICALLY ACCURATE. WE TAKE SPECIAL PAINS TO ENSURE GOOD WORKING RELATIONSHIPS BY MAINTAINING CLOSE CONTACTS, FREQUENT MEETINGS AND BRIEFINGS.

ONE MAJOR REASON FOR OUR SUCCESS IS AN INTENSIVE FOLLOW-UP PROGRAM ON OPEN SAFETY RECOMMENDATIONS. OUR HIGH ACCEPTANCE RATE BENEFIT FROM A FORMAL EXCHANGE OF CORRESPONDENCE WITH THE RECIPIENTS OF OUR RECOMMENDATIONS, SUPPLEMENTED, AS NECESSARY BY MEETINGS WITH HEADS OF AGENCIES, STATE GOVERNORS AND OTHER ORGANIZATIONS THAT RECEIVE OUR RECOMMENDATIONS.
SINCE SOME SAFETY RECOMMENDATIONS HAVE GREATER POTENTIAL THAN OTHERS, THE SAFETY BOARD HAS ADOPTED A "MOST WANTED" PROGRAM. RECOMMENDATIONS PLACED ON THIS PROGRAM LIST RECEIVE A MORE INTENSIVE FOLLOW-UP ACTIVITY IN ORDER TO ENCOURAGE RECIPIENTS TO ACT AS QUICKLY AS POSSIBLE. INITIALLY, 18 TRANSPORTATION SAFETY IMPROVEMENTS WERE INCLUDED IN THE FIRST "MOST WANTED" LIST AND THAT HAS BEEN REVISED AS THE SAFETY BOARD'S GOALS HAVE BEEN ACHIEVED.

THE SAFETY BOARD HAS USED THE MOST WANTED LIST AS A TECHNIQUE FOR HIGHLIGHTING THE IMPORTANT SAFETY ISSUES FOR THE PRESS AND THE PUBLIC. THIS IS ONE TECHNIQUE FOR KEEPING ALL INFORMED ABOUT OUR ACTIVITIES.

DURING THE FIELD PHASE OF A MAJOR ACCIDENT INVESTIGATION, WE ALSO HAVE A REGULAR PROGRAM OF THE DAILY PRESS BRIEFINGS AT WHICH WE RELEASE PERTINENT FACTUAL MATERIAL THAT HAS BEEN DEVELOPED. A PUBLIC HEARING AFTER AN ACCIDENT ALSO IS POSSIBLE AND THIS HELPS TO FOCUS PRESS AND PUBLIC ATTENTION ON THE SAFETY ISSUES INVOLVED.

I SAID AT THE OUTSET OF MY TALK THAT I FAVOR CLOSER TIES WITH OTHER INVESTIGATIVE AGENCIES. I BELIEVE THERE CAN BE IMPORTANT BENEFITS FOR US TO WORK CLOSELY TOGETHER. THIS HAS BEEN DEMONSTRATED BY OUR EXPERIENCES WITH OUR GOOD NEIGHBORS TO OUR NORTH. WE HAVE BEEN ABLE TO WORK WELL TOGETHER FROM SHARING INFORMATION ON ACCIDENTS TO JOINTLY DEALING WITH PROBLEM AREAS LIKE RUNWAY INCURSIONS.

I SEE COOPERATION AMONG ACCIDENT INVESTIGATION AGENCIES TRANSLATING INTO SAFETY GAINS FOR ALL. I AM VERY PLEASED TO SUPPORT THE INITIATION OF DISCUSSIONS ABOUT SETTING UP AN ASSOCIATION OF SUCH AGENCIES OR INVESTIGATING COUNCILS. I HEARTILY ENDORSE OBJECTIVES OF MUTUALLY ENCOURAGING THE QUALITY OF INVESTIGATIONS INTO ACCIDENTS, THE MONITORING OF FOLLOW-UP RECOMMENDATIONS AND THE EXCHANGE OF INFORMATION.

LATER TODAY I WILL SEE THE BENEFITS OF THAT EXCHANGE OF INFORMATION WHEN I TOUR THE NETHERLANDS VESSEL TRAFFIC CONTROL SYSTEM FACILITY NEAR HERE. IT IS PROBABLY THE MOST SOPHISTICATED IN THE WORLD AND I AM CERTAIN THAT WE CAN LEARN MUCH FROM THAT SYSTEM.

RECENTLY THE VALUE OF CLOSER COOPERATION WAS BROUGHT INTO SHARP FOCUS FOR ME. ON SEPTEMBER 28, THE SAFETY BOARD ADOPTED AN ACCIDENT REPORT ON A SERIES OF LOW-VISIBILITY HIGHWAY ACCIDENTS, DUE MAINLY TO FOG, IN VARIOUS PARTS OF THE UNITED STATES. THE REPORT CALLED FOR A TOUGHER, MORE UNIFORM AND COMPREHENSIVE APPROACH TO THE PROBLEM. PARTICULARLY STRIKING TO ME WAS THE RELIANCE WE PLACED ON THE EXPERIENCES MANY OF YOU HAVE HAD WITH THIS PROBLEM AND OUR REPORT REFLECTED THAT PERSPECTIVE. IT SAID:

"COMPA REO TO THE U.S., 'EUROPEAN TRANSPORTATION OFFICIALS, PARTICULARLY THE DUTCH, HAVE ACHIEVED UNIFORM DRIVER BEHAVIORS AND A REDUCTION IN SPEED VARIATION THROUGH LIMITED VISIBILITY AREAS BY IMPLEMENTING COMPREHENSIVE, STRINGENT COUNTERMEASURES THAT INCLUDE DETECTION, AUTOMATED TRAFFIC CONTROL AND ENFORCEMENT. SUCH STRICT TRAFFIC CONTROL IS NOT COMMON ON U.S. HIGHWAYS AND REQUIRES CAREFULLY DESIGNED HIGHWAY ENGINEERING PRACTICES, ENFORCEMENT, AND PUBLIC EDUCATION PROGRAMS TO MAKE IT A VIABLE COUNTERMEASURE.'"
WE ALSO HAVE A STRONG DESIRE TO WORK WITH YOU BECAUSE WE OFTEN BECOME INVOLVED WITH YOUR AIRCRAFT AND SHIPS. MORE AND MORE COMMUTER AIRCRAFT ARE BEING MANUFACTURED OUTSIDE OF THE UNITED STATES, AND MORE THAN 90 PERCENT OF THE OCEAN-GOING SHIPS IN U.S. PORTS ARE FOREIGN FLAGGED. IN ADDITION, OUR HIGHWAY AND RAILROAD INVESTIGATIVE EFFORTS COULD BENEFIT FROM THE EXPERIENCES YOU HAVE HAD.

I LOOK FORWARD DURING MY TENURE AT THE SAFETY BOARD TO LENDING MY SUPPORT TO GREATER INTERNATIONAL COOPERATION AND TO AN ASSOCIATION OF ACCIDENT INVESTIGATION AGENCIES IN AND TO WORKING WITH ALL OF YOU TOWARDS SUCH A GOAL. THANK YOU.
THE EXPERIENCE OF THE TRANSPORTATION SAFETY BOARD OF CANADA

J. Stants
Chairman of the NTSB
Canada

I am exceedingly pleased to be with you here in Delft as you celebrate the 150th anniversary of the Delft University of Technology. I am honoured to take part in this congress and participate in such a major effort aimed at advancing transportation safety.

When plans for this Safety of Transportation Congress were first mentioned to me, I began to think about my own experience and whether some of it could be of interest and perhaps even of assistance to participants in the Congress. After discussion with Pieter van Vollenhoven, he seemed inclined to think that I might have a useful contribution to make and I subsequently accepted the kind invitation to attend this congress.

To begin with, I should let you know that I am a Canadian citizen who was raised in The Netherlands including the war years and returned to Canada after the war. So, returning to The Netherlands, a country with special memories for me, is an additional reason for my pleasure at being here with you today.

As to the reason why I hope I have something to contribute to this congress, it is because I have spent a large portion of my life in activities where safety of transportation has been a key issue.

I was a Canadian Air Force pilot for many years, and was fortunate enough to gain a very wide range of aviation experience during that time in: jet fighters, heavy transport aircraft, aircraft accident investigation and flying instruction duties.

Upon leaving the armed forces I was involved in civil aviation, as an active line pilot, in management duties and as a civil aeronautics consultant.

In the civil aviation field, I was vice-president of operations, maintenance and engineering for a large regional Canadian air carrier. I was responsible for the operation and maintenance of a fleet of aircraft that operated to destinations in North America, the Caribbean, Europe and Hawaii.

In addition, in all my activities I had extensive involvement with national and international aviation organizations.

Most recently, in 1990, I was honoured to be appointed as Chairman of the then newly established Transportation Safety Board of Canada.

The Transportation Safety Board of Canada, better known as the TSB, is an independent federal agency formed to advance transportation safety in the marine, rail, pipeline and air modes of transport.
The TSB has a mandate to advance safety chiefly:

- By conducting independent transportation accident investigations and making findings as to their causes and contributing factors;
- By identifying any safety deficiencies; and
- By making recommendations aimed at reducing or eliminating these deficiencies.

The purpose of the TSB's is to find out what caused accidents so that any safety deficiencies can be reduced or eliminated and future similar accidents prevented. The TSB is not a judicial or quasi-judicial body. Its investigations are conducted not to assign fault or determine civil or criminal liability, but for the purpose of advancing transportation safety.

The TSB is an agency consisting of a board of five members including myself as a chairman, and we all have experiences in the various modes of transportation dealt with by the TSB. Our TSB staff of close to 300 people, includes many with long experience in dealing with transportation issues of various sorts, including a core of skilled professional; transportation accident investigators who have worked for many years in investigating marine, rail, pipeline and aviation accidents.

It is our experience in Canada with the operation of this independent multi-modal transportation accident investigation agency that I think may be usefully shared with all of you working so diligently to advance transportation safety. Some of our experience in Canada may be usefully taken into account by you in your efforts to ensure that in each of your countries transportation accident investigation is carried out in the best way to make a contribution to transportation safety.

To give you some idea of the work of the TSB and in particular some idea of its accident investigation capabilities, we have made a short video which I would like to run for you now.

"Video"

I hope you will have found our video interesting. Each time I see it, it brings home for me how important the work of all of us are doing in the transportation safety area actually is. Especially, it makes me realize that efforts various countries have made to establish and improve their transportation accident investigation capabilities and to make better use of the information obtained from these investigations, are without doubt one of the best investments any country can make.

I would like at the panel tomorrow to receive your questions and comments on our work at TSB so that we can discuss the issues most of interest to you all. In advance of that panel, and for those of you who may not attend it, I should perhaps just describe a few of the main features of our Canadian Transportation Safety Board and outline for you why Canada decided to adopt these arrangements for handling transportation accident investigation.
Transportation Safety

As a beginning point in Canada, there was widespread recognition of the commitment of government, industry and the public to the idea of the importance of transportation safety, over many years, ministers of transport of both the federal and provincial levels of government (because as you probably know, Canada is a federation with one central federal government and 12 provincial and territorial governments) have indicated that in the transport area, safety is their number one priority.

There has also been very widespread recognition of the fact that in ensuring transportation safety, good accident investigation practices and procedures are a crucial factor. The main function of transportation accident investigation is seen in Canada, as finding out what went wrong in order to be in a position to avoid having the same thing go wrong in the future. In other words, the main purpose of transportation accident investigation is basically to assist in preventing future similar accidents.

In Canada, it has been found that public confidence in transportation safety itself is influenced by the confidence the public has in the authority/agency which carries out accident investigation. The public wants to know that accidents are being investigated and findings made known by an objective body with no possible special "interest" in the events leading to the accident. The public, for example, does not wish to see the government department responsible for setting and enforcing safety standards for aircraft or ships also be the agency responsible for investigating an accident which may have been caused by a deficiency in this standards.

Independence - A key feature of the TSB

Following years of study and inquiries, it was established beyond doubt in Canada that the only way to ensure public confidence in the transportation accident investigation system was to establish a truly independent transportation accident investigation body.

It was felt that only such a body, completely separate from transportation safety regulators and providers of services, would be able to produce credible, objective reports on transportation accidents and make unbiased recommendations aimed at eliminating the safety deficiencies identified through its investigations. The TSB therefore was given its own act of the Canadian Parliament. The act established an agency which is as independent as any Canadian federal agency can be.

The act spells out the object of the TSB, that is, to advance safety. It clearly defines the board’s accident investigation, safety deficiency identification and recommendation making mandate. The TSB’s recommendations are not binding and it has no power to regulate or make orders. This is to maintain the TSB’s independence and objectivity.
The act gives the TSB jurisdiction to investigate accidents involving the operation of ships, aircraft, railway rolling stock and pipelines.

Our enabling legislation specifies certain methods of operation for the TSB to ensure that accident investigation and the development of reports on the board's finding are done in an open and fair manner. As well the TSB investigators are given a wide range of powers under the legislation, powers which enable them to obtain all the information they need to assist in determining why accidents took place and to identify safety deficiencies.

The enabling legislation makes very clear the independence of the board and its separation from other government agencies. The object of establishing a conflict free body, has been well achieved. The act specifies that the TSB will report, not to any one minister, but to the Canadian Parliament. The TSB reports to Parliament through the president of the Queen's privy council for Canada, not through the Minister of Transport. This is seen as a very important arrangement, as it fully separates the TSB from every federal department and Minister, including those responsible for transportation safety regulation and any others which could be seen as having a real or potential conflict of interest with transportation accident investigation.

Uni or multi-modal agency? Which arrangement is best?

From the beginning of serious discussion of a need for sound independent transportation accident investigation in Canada, it was recognized that there was a need in all modes of transport to ensure such good independent transportation accident investigation took place.

In every mode of transportation, including the air, marine, rail, road and pipeline modes which are within the TSB jurisdiction, and in the highway mode as well, good accident investigation is equally important to advance safety in each mode.

I should perhaps explain here why TSB was not given responsibility to investigate highway or road accidents. The reason for this lies in the division of powers under the Canadian constitution. With our constitutional arrangements, highway and road safety matters are largely the responsibility of the provinces and a federal agency, such as the TSB, cannot be given responsibilities in these areas of provincial jurisdiction.

It may be that in the future, the TSB mandate will be extended to include some highway accidents where federal jurisdiction is involved; this could only be for accidents involving trucks and busses moving between provinces or internationally.

Recognition of the need for independent investigation in every mode, it was also recognized that there were various approaches which could be taken to introducing a truly independent accident investigation capability for each mode. For several reasons, it was decided that the most effective organizational option to choose, for Canada at least, was to establish one multi-modal agency with authority to investigate transportation accidents in the several federally regulated modes of transport.
The main reasons why it was felt one body with multi-modal jurisdiction could do a better job than would be done with establishment of several agencies, each with jurisdiction in one mode only were:

1. It would be easier with a multi-modal body to ensure Canada's accident investigation policies and procedures were consistent with respect to accidents in each mode; thus, the same treatment could be expected for those involved in air, marine, rail or pipeline accidents. In Canada it was felt that it would be almost impossible to achieve this consistency if separate agencies were established, as each agency would have its own interpretation of its enabling statute and its own way of operating in areas of discretion.

2. With a multi-modal agency, the possibilities for each mode to learn from the experience of the others would be greatly enhanced; at TSB we are finding this to be a particularly important area, with great gains to be made in terms of the ability to advance safety. Lessons learned from work carried out in technical areas such as engineering and medical and generally work done with respect to the human factors elements of investigations, and statistical analysis are useful with respect to investigations in all modes.

3. Of course, there would be administrative efficiencies and cost savings with one agency rather than separate ones. Resources saved in this way could be re-directed into doing better or more investigations and related work in the development of sound safety recommendations.

At the same time, it was recognized in Canada, that in a uni-modal agency, there would be the advantage that the mode in question would be the principal focus of the whole agency. In each mode, industry, accident investigators and regulators were concerned that with establishment of a multi-modal body, some modes might receive less attention than others or that the attention given might not always be appropriate.

These real concerns were felt to be more than outweighed by the advantages listed above as being involved in establishment of a multi-modal board. Nonetheless, the concerns were real, and the legislation passed to establish the new multi-modal board addressed them.

The legislation provides that, when the board members are appointed, the governor in council (who does the appointing) must appoint as members, persons who, in the opinion of the governor in council, are collectively knowledgeable about air, marine, rail and commodity pipeline transportation.
Another section of the legislation which is designed to ensure adequate and full attention to each mode, is the section which provides that for each of the air, marine and rail/commodity pipeline modes a separate director of investigations will be named. Thus, at TSB there are separate branches under the leadership of three directors, and each branch handles investigations in its own mode of transport by use of investigators long experienced in each mode in question.

So, in the parts of our work where it is important to have the unique expertise developed in connection with an individual mode of transport we have it.

In areas where knowledge is shareable amongst modes, we are in a position to share it easily. For example, in the area of human performance as it relates to transportation safety, knowledge can be shared. This area, as all of us here know, is becoming increasingly important and an area of focus as all countries try to improve their transportation safety records. Similarly, in the engineering area, much knowledge can be shared.

Likewise experience gained in investigations and analyzing factors involved in accidents in one mode and developing safety recommendations with respect to them, is valuable as we develop recommendations aimed at avoiding accidents in other modes which may have involved similar factors.

Other aspects of work related to transportation accidents investigation are also transferable amongst modes. For example, the techniques used to analyze the evidence obtained during investigations and to communicate safety information are similar whether we are dealing with marine, rail, pipeline or aviation accidents.

**Implementation or getting there**

Once decisions were taken in Canada to establish an independent multi-modal transportation accident investigation body, it proved to be a complex and time consuming task to implement these decisions.

In effect, these decisions has been made as early as 1972, but it was not until March 1990 with establishment of the TSB that there was full implementation of a truly independent multi-modal accident investigation and safety body.

There are many reasons why establishment of such a body involved a long process in Canada and why it would likely be a challenge to establish such a body in any country.

Fortunately, in Canada we had the example of the US National Transportation Safety Board to follow, and many aspects of the NSTB are adopted and recognizable in our Canadian agency.

Much good will and effort, and good timing, are required to achieve establishment of an independent multi-modal accident investigation agency.
In Canada, as things worked out, as a first step, a single mode agency was established in 1984. This was the uni-modal agency known as the Canadian Aviation Safety Board or CASB. As the name implies, CASB had jurisdiction with respect only to aviation accidents. The government of the day which brought forward the enabling legislation for CASB, indicated at the time that this was a first step only and that it was that government's intention to follow up with similar arrangements for ensuring independent transportation.

**Accident investigations in other modes as well**

Some time elapsed before this could be achieved, and it was another government which, in 1988 and 189 tabled legislation for our multi-modal board.

One significant factor which led to delays in establishment of these agencies was the need for the federal government to deal with the natural reluctance of those with close interests in the matter to accept a change in the status quo and re-arrangement of responsibilities.

In each mode, the various interested groups including carriers, regulators, employers and employees and passengers and others who had a direct interest in transportation accidents, including coroners and police, all had a different perspective on how best to approach the matter of ensuring good accident investigation for the purpose of advancing transportation safety. The need to take all these points of view into account and develop a good balanced response was time consuming in Canada.

Any country intending to establish such an agency will now be able to learn from experience both with our TSB and the US National Transportation Safety Board.

I personally will be more than pleased to share our TSB experience with anyone who is contemplating establishment of an independent transportation accident investigation and safety body. I will also be prepared to make available the expertise on our TSB staff in this area.

**International Cooperation**

This naturally leads to the topic of cooperation and sharing knowledge in transportation accident investigation and related areas. This includes not only sharing information concerning establishment of independent accident investigation bodies, but to sharing of substantive safety related information obtained from investigating accidents. As well, the sharing of accident investigation techniques and technologies is especially important and useful.

We have found at TSB that through such international cooperation, enormous strides towards advancing transportation safety can be made.

At TSB we consciously devote significant resources to international cooperation efforts, as we find that the resources expended are very productive in terms of advancing transportation safety.
In the aviation and marine modes, TSB is active in sharing information and promoting various initiatives internationally. This is done on an individually country to country basis and by participating in aviation and marine international associations such as the international society of air safety investigators (ISASI) and the newly formed marine accident investigators international forum. We are also active in the official United Nations organizations devoted to aviation and marine matters, the International Civil Aviation (ICAO) and the International Maritime Organization (IMO).

For example, one area in which the TSB engineering branch has developed very useful expertise is in the use of flight data recorders and cockpit voice recorders to analyze and prepare graphic depictions of aviation accidents. The techniques developed at TSB, those which use computer software for the analysis of FDR information, have given TSB an unusual flexibility in the recovery of data. TSB often shares this expertise with other countries and provides assistance in connection with major aircraft accidents when those investigating the accident have difficulty with FDR readout.

Some accidents where TSB expertise and services (and those of TSB’s predecessor CASB) have been helpful have involved the following:

- DASH 8; Bangkok, Thailand
- B 737; Cayman Islands
- B 767; Sweden
- BAC 111; Nigeria
- DC-8; Saudi Arabia
- Twin Otter; Norway
- B 747; Lockerbie, UK
- Airbus A310-304; Nepal
- A320-300; Nepal
- B 747-237; Ireland

(This crash of an Air India flight from Canada to India was the subject of a major investigation by an Indian Commission of inquiry led by Mr. Justice B.N. Kirpaul. In his report, judge Kirpaul stated that it was only with Canadian help that "... The court was able to obtain evidence and information relating to the accident. Without Canadian help the conduct of the investigation would have only been speculative in nature").

The FDR readout capability is a good example of the sort of information on transportation accident investigation which lends itself to being shared with other countries. To date the US, France, Germany and Australia have found it helpful to make use of TSB software.

I am proud of TSB’s work in this area, and very pleased to have been able to share it internationally. I believe development of this software and discussion of it has been instrumental in advancing international standardization and thus advancing transportation safety.

Another TSB initiative which indicates the importance of TSB places on international cooperation, was the marine accident investigators forum organized by the TSB director of Marine Investigations in June of this year.
A three day meeting was held in Ottawa, Canada, with 19 senior Marine accident investigators and one observer representing 17 countries. This was the first time marine accident investigators from around the world gathered together. The main purpose of the meeting was to see whether a permanent international forum for Marine accident investigators would be useful. At the Ottawa meeting it was agreed that a permanent association would indeed be useful, in line with the spirit of the International Maritime Organization (IMO) Resolution A637 (16) which calls for cooperation in those casualty investigations with international implications. The new organization, to be known as the Marine Accident Investigators International Forum, will hold its next meeting in May in Cyprus.

In this vein of international cooperation, I strongly believe that an international federation or council of independent transportation accident investigation agencies could play an invaluable role in promoting transportation safety worldwide. I hope this congress will be instrumental in leading to establishment of such an association.

Within such council, countries which have extensive experience in accident investigations of a particular sort can share that experience with countries which may have a more limited experience. An international council would be able to draw on the resources of all participating countries to provide expertise and data and advice, which could help in carrying out investigations.

Conclusions

I have tried to cover Canada's approach to the four transportation safety issues which are closest to my heart, and which are also the themes of this congress, that is:

1. The importance of transportation safety
2. The importance of independent investigation of transportation accidents
3. The benefits of a multi-modal approach to transportation accident investigation
4. The benefits of international cooperation in the transportation accident investigation area

I am grateful to you for the opportunity to discuss these points with you, points which I know are also of importance to you all. I hope that knowledge of Canada's experience in these matters will be helpful to you.

I will be pleased to have further discussions at tomorrow's panel when I can answer any questions you may have and share TSB information or experience that you might find useful.
ROAD DESIGN
Roundabouts have become very popular in the Netherlands over the last couple of years. There can be made a difference between three types of roundabouts: the mini, the midi and the large scale roundabout. It can be noticed that the various types are used quite indifferently on different locations in traffic networks. The driving skills of the various road users are limited. Driving tasks are very different on traffic arteries then in environmental areas. The application of functional theory of driving behaviour and more specifically the human performance model, which makes a difference in three levels of cognitive functioning, pleads for consistent design. Designs should be adjusted to the driving tasks required in either environmental areas or on traffic arteries. The application of the theory leads to design suggestions for the three types of roundabouts.

1. Introduction
The concept of the roundabout has existed for a long time. In the beginning of this century roundabouts were used at busy intersections where there were more than 4 legs. The location of these roundabouts was usually in the centre of busy urban areas. Roundabouts could therefore be found around important city-squares. This type of application for roundabouts was found in a number of countries, such as England, France, USA and the Netherlands. Following the successful application of the roundabout in downtown urban areas, their use was extended to complex road intersections. In England especially, they became the dominant design at intersections. This development took place in the 1960’s and 1970’s. Roundabouts became even more popular after the change of priority to a give-way to traffic from the right regulation. In England extensive use has been made of the mini roundabout principle. Many different designs have been tested and the safety and capacity record of these designs is satisfactory. The designs were based on the principle of the separation of converging traffic streams and locating them in such a way that capacity was maximized by the use of multilane convergence areas.

Until 1980, roundabouts in the Netherlands were applied only at large scale junctions in motorways. The design standards of large scale roundabouts in traffic areas were determined by the capacity demand. Therefore the outer and inner diameter is large in the square application as well as in the motorway junction solution. The traffic flows and driving demands were governed by the principle of 'weaving'. In the Netherlands the popularity of the so called midi roundabouts took place in the mid and late 1980’s. These midi roundabouts were applied both in and outside urban areas. With the introduction of the midi roundabout in the Netherlands, which in size are between the mini and large scale roundabouts, questions arose about the safety of these roundabouts (Van Minnen, 1989). There are two main differences between the English and Dutch situation:
- in the Netherlands large numbers of cyclists are present in urban as well as rural areas.
- in the Netherlands, the driving discipline, especially during weaving manoeuvres isn't so good as in England.

There are strong indications that roundabouts are safer than signal-controlled intersections. Conclusions following research about safety on
roundabouts by Van Minnen (Van Minnen, 1990), show that particularly car-cyclist accidents occur less often. There are indications that safety in terms of absolute numbers for car-cyclist accidents is also improved on roundabouts. In general, one may say that roundabouts do improve traffic safety, with the exception that for cyclists the subjective danger may be just as great on roundabouts as at a normal 4 leg junction. Therefore a closer look at roundabouts will be very useful.

2. Problem definition

In the Netherlands, the discussion about roundabouts is not yet finished. In particular, their influence on the safety of cyclists and pedestrians is also not yet fully clear. The discussion centres on both the design and the application of roundabouts. The development of roundabouts in the Netherlands has been turbulent. For a long time roundabouts were considered 'second rate'solutions, except in the form of large scale traffic circles, which were regarded as priority roads and which were controlled by signals when traffic volumes grew. In the late 80's different type of roundabouts were constructed. Throughout the country they were applied in traffic regimes, such as environmental areas, traffic arteries and as a "gate" symbolizing the entry to villages and such. In addition the priority regulation wasn't the same for all roundabouts.

At the moment, one could categorize the roundabouts in the Netherlands into three types of roundabouts:

1. Conventional large scale roundabout. These are roundabouts with central islands with more than one lane and mostly equipped with traffic signals.

2. The "midi" or basic roundabout. This roundabout type is the most popular and usually has one lane and a central island of about 10 meters. The total diameter is of 25 - 30 meters.

3. The small or mini-roundabout, which is smaller than a midi roundabout. The central island is often no more then a marker for turning traffic.

Traffic on the conventional and midi roundabout generally has priority over the entering traffic. Traffic leaving the roundabout has to give way to traffic on the roundabout or following the course of the roundabout (c.q. cyclists on separate cycle-lanes.)

As already mentioned these three types of roundabouts have many variations in their lay-out and regulation and are applied in various kinds of situation. There are many differences in construction form, such as the presence or not of a lane for cyclists, etc. This has caused some confusion about the application of roundabouts in traffic protected areas and on traffic arteries.

The differences between roundabout types and the location of various road environments, together with the differences in the construction of roundabouts, confuse road users in their driving tasks. This can lead to unsafe situations. A central problem is to decide which combination of application type, construction form and location within a specific road environment, best fits the driving tasks of the various groups of road users passing through a roundabout.

3. Driving tasks for the various road users.

Traffic safety depends to a great extent on the proper execution of the driving tasks of various road users. The question now arises as to how the concept of driving tasks can be applied on roundabouts. The driving tasks
comprise different subtasks, such as finding the proper direction, following the road and avoiding collisions. Driving tasks are executions of actions which result in observable behaviour. Some of the aspects that influence the quality of the execution of the driving tasks are; detection of information, anticipation, information processing and experience. The importance of analysing driving tasks is that once the determining factors of driving tasks are found, it is possible to influence the execution of these tasks in such a way that the desired traffic behaviour results. By understanding and analysing driving tasks, it is possible to design better traffic solutions, including roundabouts, based on expected behaviour. The prediction of expected traffic behaviour should take into account the possible conflicts that can occur and the validity of the preferred solution.

The driving tasks can be separated into levels at which the execution of these tasks is based. At the lowest level road users try to avoid conflicts. The subtask of reaching the intended destination lies at a higher level. It is obvious that road users try to avoid conflicts from an instinct of self-preservation but on the other hand they try to reach their destination in as short a time-period as possible. As a consequence there can exist a conflict of interests between various driving tasks. This conflict can be tempered by a well-designed traffic solution.

The driving environment is important for the quality of execution of driving tasks. Quality can be defined as the the absence of conflicts or accidents and by the the level of stress (subjective traffic safety). In general, the driving environment will either emphasize the driving tasks of reaching one's goal or the task of avoiding conflicts or collision with other road users. In the first case, the designer will try to avoid as many conflicts as possible in order not to impede traffic. He will separate the various kinds of road users. In the second case he is not able to avoid conflicts and will therefore try to increase anticipation levels and thus avoid conflicts. He will, therefore, in general stimulate adjuncted traffic behaviour by forcing a shared use of the roadway.

There are many theories about safety and driving tasks of road users. One that tries to explain safety errors by differences in cognitive functioning is the human performance model developed by Rasmussen (Rasmussen, 1981; Hommels & Hale, 1989). In this model, differentiation is made in three levels of abstraction of behaviour. Each of these represents an abstraction of behaviour, which is of importance for the driving tasks.

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>COGNITIVE FUNCTION</th>
<th>BEHAVIOUR</th>
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</thead>
<tbody>
<tr>
<td>knowledge</td>
<td>interpretation</td>
<td>evaluation</td>
</tr>
<tr>
<td>rule</td>
<td>identification</td>
<td>procedure</td>
</tr>
<tr>
<td>skill</td>
<td>observation-activation</td>
<td>execution</td>
</tr>
</tbody>
</table>

At a skill level, the incoming information is translated directly to a specific response. This response is activated by the prestored patterns of preprogrammed instructions. These can be executed without the driver's realization of this or having control over the executed tasks. At this level, the driving task requires no interpretation and little feedback to achieve the goal, because the skill action is known through its frequent use.
Take as an example a cyclist who wants to turn left. The cyclist is familiar with the route and has been driving the route hundreds of times. He will automatically look behind him and gather information. This information will then be processed based on his previous experiences. In case no automatic response fits the information or when other responses on the obtained information are possible, a more conscious approach is required for executing the driving task. The cyclist will no longer be able to react at a skill level, but will have to process the information on a rule-base level.

The difference with the skill level lies in the degree of familiarity. On a rule-base more alternatives are at hand. All alternatives have some familiarity and the cyclist will, depending on the situation, make a choice out of the alternatives available. If a new or unknown situation appears, the cyclist has to solve the problem with constructive thinking. For these situations, new actions have to be made based on the already present knowledge about the situation.

Bearing this in mind one can look upon the driving tasks from the viewpoint of each subtask: avoiding conflicts or reaching one's destination. The human performance model can be helpful for the description of the driving environment and for the analysis of errors made according to the human performance.

4. Application of the theory on roundabouts.

4.1 The car driver
When a car driver approaches a roundabout he has already a concept on the function of the roundabout and of the conflicts to be expected. He has derived that concept from the driving environment. If he is coming from an environment where separation of traffic and elimination of conflicts has been the rule, he might get into problems if the roundabout doesn't fit this image. E.g. if he only focusses on car traffic when he comes from a situation where conflicts between other groups of road users are eliminated, he may "forget" the presence of bicycles.

The car driver approaches the roundabout at a certain speed and has to slow down. He has to identify the priority-situation within clues from the environment (traffic sign and markings). When he has to stop he has to focus his attention on other cars on the roundabout and on cyclists. After entering the roundabout he has to follow the prescribed route. The driver's attention is attracted by the circular lay-out of the roundabout and by the problem of following the road to the right destination. This can divert the driver's attention away from the cyclists to the right of him. If he makes an error, he makes a mistake on a rule-based level and will use a wrong procedure (Reason, 1982). A turn to the right requires the use his mirror in order to identify slow traffic on the right. This process can go wrong if the driver fails to identify the presence of cyclists or pedestrians.

4.2 The cyclist
The cyclist also has a concept on the roundabout. Critical in the driving task for the cyclist is the fact he has to maintain his equilibrium and to follow the road, while keeping track of car traffic both behind and in front of him. This can cause problems on both skill and rule-based levels. E.g. the cyclist can hesitate reacting for car drivers the impression that he will yield priority or that he can be blocked out of the anticipation zone.
There are three kinds of mistakes that relating to the human performance model can be made. Mistakes on a skill level, rule level and knowledge level. The last two errors can blend together and may reinforce each other. Skill based errors are related to the driving environment. Therefore the principle of separating/mixing of road users has a great influence on the notion of the environment. Skills are learned after knowledge at rule level is digested by the drivers mind. The notion of the driving environment in the drivers mind must therefore correspond with the traffic environment that has been designed (Theeuwes, J., Godthelp, H. & Riemersma, J., 1992). This is important, because it is only by this reaction to the traffic situation that the driver can "see" from the environment whether he has to adjust his skill. Therefore elimination or presentation of conflicts on roundabouts should automatically be deduced by the driver from the driving environment, which itself results from the way the roundabout has been designed.

Rule/knowledge based errors are made when situations aren't really clear to the various road users. Consequently when the wrong choice is made from several alternatives, then the roundabout probably wasn't designed well. It is also possible that too much time is spent in finding by the driver the right procedure or, in a knowledge situation, in creating a new solution. In such cases information picked up by the driver concerning the traffic situation is probably ambiguous.

Solutions for such skill-based errors have found to be found in the driving environment: it must be made clear to all road users what conflicts to expect and they must also know what options they have and how to execute the behaviour that is required. The solution for rule/knowledge based errors is to provide clear, obvious signals on how to behave. This can be done by using the right materials, good sight-distances, high standard of design and a good use of the priority rules.

More reaction time is required on rule based level. Therefore signals must be given at a greater distance, if this distance is not available than speeds have to be reduced. This can be the case in environmental areas. If speeds are higher, such as on traffic arteries, a long anticipation distance is necessary. In case mistakes are made by the drivers, the design must also provide sufficient space for escapes.

The execution of the driving task by car drivers will be influenced by their anticipation of the traffic situation. Conflicts with slow traffic will be more frequent when traffic conflicts are eliminated on the approach roads. As for the conflicts, they will be more unsure in the execution of their driving task when traffic speeds and volumes on the approach roads are higher.

This leads us to the statement that the driving environment has a considerable influence on the behaviour road users. One could therefore plea that roads should be subdivided into two main categories:

- environmental areas: areas where the main driving task is "avoiding conflicts".
- traffic arteries: areas where the main driving task is "reaching ones destination by following the road".

Such a subdivision has already been made in the Netherlands. The application of such a categorisation has not always subsequently been effected. The design of roundabouts has also not been adjusted accordingly. In environmental areas, traffic should be mixed and conflicts should
therefore be presented and expected. Car-traffic is a "guest" in these areas so it should be made obvious that speed must be low, because conflicts can be expected and one has to yield other road users. The recognition of such a situation should not mean that an uniform design has to be used but that uniform rules for executing the driving tasks should be established actions are asked. They imply "standard behaviour"; so that car drivers and cyclists can use the right skills to cross these areas.

On traffic arteries the elimination of conflicts and the separation of various road users should be standard. Designs and solutions in these surroundings should be uniform, so that the right skills will be used. If in a new situation there is doubt about what behaviour should be required, the road user should be able to solve this problem on a rule based level. The designer should avoid situations where the road user has to act on a knowledge base because of the time-distance-direction consequences.

5. Categorising roundabouts: network aspects.

As already mentioned, the use of roundabouts in the Netherlands has been more frequent recently. Roundabouts are used for different reasons. One reason is that the original intersection is a black spot location. Other reasons are that there are many accidents resulting from conflicts of priority, or that speeds are too high and have to be reduced. Decisions about the use of roundabouts aren't looked at solely from the view of the driving tasks and the driving environment but are mostly decided upon arguments relating to the "solution side" of the problem.

In the Netherlands three different types of roundabout can be found at different types of locations. Field observations show that a midi roundabout can be found to exactly the same design on a 80 to 50 km/h intersection as on a 30 to 50 km/h intersection. Observation also show that significant differences in the design can be found in the same type of roundabout used at similar locations. The differences are e.g. the diameter, the use of materials, the priority regulation, vegetation on the middle island, etc. All these differences generate a great "hocse" in the signal and can be the source of errors at skill and rule level.

In the future the application of roundabouts has to be determined by the type of area where they will be applied. Roundabouts should be looked at from the perspective of the influence on driving tasks and driving environment. For environmental areas it can be said that presentation of conflicts and mixture of groups of road users is inevitable. The kind of roundabout that should be used in these surroundings, is the small roundabout. This type of roundabout should have no priority regulation so that the presentation of conflicts are made obvious. It is not necessary on this type of roundabout to separate the road users, obviating the need for no separate lanes for cyclists. The design should speak for it self here. No help should be needed from signs or other legal regulations. In case where there are heavy flows of traffic, a roundabout should not be used. In such cases intersections should be designed as "attention"-points.

On traffic arteries where traffic should be separated and conflicts eliminated roundabouts should have a standard priority rule, which should be to give-way to traffic from the right. Cyclists should not be allowed on the roundabout. According to the situation, one or two lanes for motorised traffic can be used. In such case cyclists should be diverted around the roundabout on separate cyclelanes. Traffic on these lanes can be given
priority above exiting traffic. In the case of very intense traffic flows, the priority might be reversed.

On connecting roads and streets, between traffic arteries and environmental areas, the problem is to decide on the relative importance of: the separation of road users and the elimination of conflicts or whether to allow the mingling of different types of traffic and accept the resultant presentation of conflicts. For reasons of safety and to set the tone for a more friendly driving environment a mixture - presentation roundabout seems to be the best solution in such cases. This type of roundabout can be designed as the so called CROW basic roundabout (CROW, 1989). This is a one lane roundabout with a cyclists lane on the roundabout, preferably marked with red tarmac to accentuate the position of the cyclists. The roundabout should indicate the priority rule.

An example of how different types of roundabouts are applied, can be found in the city of Tilburg where different kind of roundabouts can be found at different kinds of location. Comment can be made especially on how midi roundabouts are used at different kinds of location (see figure 1). On the traffic arteries of the city Tilburg, midi-roundabouts are mostly found. These roundabouts differ in design, although they are situated in similar environments. These roundabouts sometimes mark the crossing of two traffic arteries and sometimes the crossing of traffic arteries and environmental streets but within an environmental area midi roundabouts are found as well. These roundabouts have priority regulation with signs, which is not according to the general rule in this kind of environment.

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**Figure 1.** Traffic network Tilburg with locations roundabouts
6. Design suggestions
The foregoing has been argued for the use of a specific kind of roundabout in a specific area. In the following some designs are presented illustrating the principles of separation - elimination or mixture - presentation.

6.1 Mini-roundabout
On this kind of roundabout presentation of conflicts and mixture of road users should be the design rule. The roundabout should not be too big, otherwise speeds will not be reduced and the roundabout will be particularly unsafe, because of the many conflicts between different road users. The roundabout should be just big enough to accommodate a garbage truck. The vehicle must be able to navigate the roundabout at low speed. The most important design feature is the accentuation of the intersection, so that road users can detect what skill or rule has to be used.

The analysis of the driving tasks can be focussed on approaching, rounding and leaving the roundabout. In the approaching phase, car drivers have to reduce speed, note the attention point in front and start procedures for rounding/crossing the roundabout. Errors can be made e.g. by approaching the roundabout at too high a speed or coming into conflict with a cyclist by leaving the roundabout. The designer must eliminate such errors by designing the lane on the roundabout so that cyclists must ride in front of the car and overtaking must be made difficult. Conflicts between turning cars and cyclists can thus be less serious. If a conflict between a car and a cyclist occurs speeds will be very low so subsequent accidents will not be too serious. An example of a mini roundabout is given in figure 2.

figure 2 and 2a. Mini-roundabout

6.2 Midi-roundabout
The design of roundabouts at crossings of traffic arteries must follow more strict design rules. Separation of road users must be strived for. For transit areas conflicts between perceived functions from the biggest proportion, because some road users come from an environmental area and some from a traffic artery. The design has to bring out the right skills and procedures by the various road users.

A roundabout will be used in this situation as an attention point. For road
users from the traffic artery it is brought forward, through the round form of the roundabout which is not much used in traffic arteries, that they are approaching a special point. The same can be said for road users who come out a environmental area. To them, it must be made clear by the design of the roundabout, that the environmental area stops at that point. So for road users out of the environmental area skills tuned to mixture and presentation has to change to skills tuned to produce an efficient traffic flow.

For road users on the arteries, separation and elimination is the case. The design of a roundabout should help to overcome the differences in skills and rules. Figure 3 is an example of a midi-roundabout. Cyclists are allowed on the roundabout but on a separate lane. Therefore mixture-separation is not really achieved but use of the lane is stressed by giving it a different colour, such as red. The drivers will be informed on the priority rule on the roundabout. The priority rule is also made clear by means of signs and markings.

figure 3. A midi-roundabout

6.3 Large scale roundabouts

Roundabouts in traffic arteries must be designed on the principle of the separation of road users. Cyclists should not be "mixed" with car-traffic. It is important that priority rules on the roundabout are the same as those on normal intersections. This is because skills will be executed automatically on this basis in this environment. Therefore cyclists should be given priority over car traffic leaving the roundabout.

Conflicts between cyclists on the roundabout and cars leaving the roundabout should to be avoided. To make this situation work cyclclanes should follow the roundabout in a concentric way, thus keeping the cyclists in the sight of car drivers. The conflict remains but is less grave because the car driver can better focus on the cyclist when he approaches the roundabout, then focus on the other cars and the weaving on the roundabout and then on leaving the roundabout he can focus on the cyclist again. By
separating these different conflict points in space and time the driving task for the car driver becomes less stressful. The driver is thus not saturated with information and is not pressured to perform all these tasks simultaneously. It is important that the various conflict points are well marked and particular stress should be given to visibility. The visibility angles are therefore most important. Figure 4 gives an example of a large scale roundabout.

figure 4. A large scale roundabout

7. Conclusions
* For the designer of roads and streets the choice between two design strategies is of the utmost importance: traffic artery or environmental area. Road categorisation is necessary.
* In practice standards of design and design solutions are made, regardless of the immediate surroundings and the function of the road. The designer must make a firm stand on either of the two design strategies and implement them in a structured way. The designer should not divert from the selected integration for reasons of opportunity.
* The designer must make the driving tasks of the various road users the basis of design. He should analyse the driving tasks in detail and make ample allowance for the limited driving skills of the various road users.

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SELF-EXPLAINING ROADS

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Abstract

This paper discusses the concept of a structurally safe traffic system. The crucial question is how potential errors occurring in traffic can be reduced by revising the lay-out of the road environment. Two considerations play an important role: inherent safety and self-explaining properties. Inherent safety refers to the reduction of potentially dangerous encounters. Traffic systems having self-explaining properties are designed in such a way that they are in line with the expectations of the road users. The in this paper discussed "Self-Explaining Road" (SER) is a traffic environment which elicits safe behavior simply by its design.

Introduction

One of the major problems of road traffic is its level of unsafety. It is commonly estimated that over 90% of the traffic accidents are related to human error. Because better education, information and enforcement only have a marginal effect on accident reduction, it is crucial that the road and vehicle environment is adjusted to the human capacity limitation. Safety should be considered as a system property to be built into the road and vehicle environment (see e.g., Godthelp, 1990; Roszbach, 1990; Twisk, 1991). The crucial question is how design principles can reduce the probability of an error when executing the traffic task. Two aspects play an important role: inherent safety and self-explaining properties. Inherent safety refers to the reduction of potentially dangerous encounters. Traffic systems having self-explaining properties are designed in such a way that they are in line with the expectations of the road user. The so-called Self-Explaining Road (SER) is a traffic environment which elicits safe behavior simply by its design.

In recent years, the TNO Institute for Perception has studied several aspects of Self-Explaining Roads. For example, Riemersma (1988) investigated how drivers

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1 This paper is prepared from a more extensive report commissioned by the Netherlands Ministry of Transport and Public Works (Theeuwes & Godthelp, 1992). The authors would like to thank H v.d. Colk, M.P. Hagenzieker, J. Hartman, J.H. Kraay, P. Levelt, P. C. Noordzij, M. Pol, and E. Tenkink for their collaboration.
internally represent different road categories. Theeuwes (1989, 1990, 1991a) investigated the role of drivers expectations on search strategies in traffic. Recently, Theeuwes & Godthelp (1992) applied the principles of enduring a safer road environment on rural 80 km/h roads, and inferred a list of design criteria for the development of SER.

Categorization of road environments

The idea that road users categorize the traffic environment is based on the general notion that people try to structure their world. It is not the individual objects, nor the individual environments that will be stored in memory but an abstract representation of the world which contains a basic set of typical properties. These prototypical representations develop through experience. In order to ensure unity in the way people structure their world, it is required that there is a large consistency in the physical appearance of an object or environment and a large consistency with respect to the behavior displayed in relation to that object or environment. When these conditions are fulfilled, it can be expected that the prototypical representation of a certain object or environment will be more or less the same for everyone. For example, for people from the Western world there will be a large consistency with respect to the prototype of a chair: an object with four legs, a seat, a back; the typical behavior is that one can sit on the object. When confronted with another object (e.g., a stool; a high seat without a back) which physically does not resemble a typical chair, categorization of that object as a "chair" will be less easy. It should be noted that objects can also be solely classified according to the behavior in relation to an object. For example, a "bag" on which one can sit comfortably but which does not at all resemble a typical chair, might still be classified as a chair.

It is reasonable to assume that through experience road users will develop a prototypical representation with respect to the different types of roads. When the physical appearance of a specific road environment is homogeneous and physically different from other types of road environment, it is expected that a prototypical representation will easily develop. For example, if one would ask road users to describe a freeway then there will be consistency with respect to the type and the position of the road elements, road users and the relationship among them. If such a question would be asked with respect to the 80 km/h roads outside the built-up area, there will be not much consistency in the answers, because there is no coherence in the physical appearance of these types of roads; nor is there consistency in the behavior displayed on these type of roads. In addition, when there is not much consistency in the physical appearance of a specific type of road, road users might develop a biased prototype which reflects the type with which the road user happens to have a lot of experience: for example, the 80 km/h road which a road user takes every day to work. This biased prototype might be inadequate in other 80 km/h road situations.
Riemersma (1988) investigated subjective road categorization as represented in the "heads" of the road users. For the built-up area, the results indicate that the official objective criteria of road categorization as used in the design of road environment is only marginally present in the subjective categorization. In addition, the study shows that the estimated safe speed depends only on the effort it would require to keep the car on the road. The probability of the occurrence of an encounter with another road user (e.g., pedestrian) did not have an effect on the estimated safe speed. Outside the built-up area, Riemersma (1988) demonstrated that the emergency lane which, in the Netherlands discriminates freeways from other types of fast roads, is not used in the subjective categorization. In addition, roads which were not freeways but which allowed a high speed were often erroneously classified as freeways (15-20%).

Mazet & Dubois (1988) claim that the categorization of road environments occurs only on the basis of the behavior displayed in these environments. This implies that different categories of roads that generally require the same type of behavior will subjectively be represented by the same prototype. A residential area where everybody drives 80 km/h (although the speed limit is 50 km/h) and a city highway where the same speed is utilized will be categorized in the same way, although they look quite different. Inadequate categorization is dangerous because the inadequate categorization will induce inadequate expectations.

The effects on traffic behavior

The prototypical representation of traffic environments which is the basis for the categorization process contains 'information' regarding the typical spatial relationships between the road elements and road users, so called schemata (Bartlett, 1932; McClelland & Rumelhart, 1981); and 'information' regarding the typical sequences of events in time, so called scripts or frames (Minsky, 1975). Classification of a road environment activates particular scripts and schemata which, in their turn, induce where—in place and in time—particular road users and elements can be expected. If the environment induces inappropriate expectations, errors in visual selection are likely to occur.

The nature of contextual effects on the processing of traffic scenes is thought to be the result of an interaction between incoming perceptual information and the higher level memory representations (i.e., schemata and scripts). For example, it has been demonstrated that objects that are obligatory in the schema are encoded more or less automatically (with a minimum use of the processing resources), whereas objects which do not fit in, require more resource-expensive encoding processing involving active hypothesis testing (Friedman, 1979). Loftus et al. (1983) argue that scenes are processed in two stages. Holistic information is extracted first, followed by search for specific features. The holistic information can be assessed within a single fixation of the scene (Potter, 1975). This
information is thought to activate the scene schema which is held in a presumed pictorial memory system (Paivio, 1971). A search is then initiated for specific objects as held in temporal storage.

Recently, Theeuwes (1991a) demonstrated the effect of contextual information on visual search in every-day life traffic scenes. More specifically, the study explored the effect of the object-context relation "position" as defined by Biederman et al. (1982). This property refers to the fact that objects which are likely to appear in a given scene often occupy specific positions in that scene. This effect on "position" information is particularly important because this relation might be violated in every-day life traffic situations. Theeuwes (1991a) showed that errors evolved when road users had wrong expectations regarding the location appearance of particular target objects. Figure 1 gives an example of the stimulus material used in this study.

With respect to this example, subjects were instructed to search for a traffic sign and respond "yes" when they found it and "no" in case they thought that no traffic sign was present. In the upper picture, the traffic sign is positioned at an expected location which gave a search time of 1112 ms and 6% errors. In the lower picture, the traffic sign is positioned at the left side of the road which is an unexpected location given the overall lay-out of the scene. In this condition, search time was 1745 ms and in 33% of the cases subjects thought that no traffic sign was present. Since both pictures are physically identical, that is, the conspicuity of the traffic signs is exactly the same for both pictures, the difference in performance can only be attributed to the top-down driven search strategy induced by the lay-out of the scene. Figure 2 gives the mean reaction time and error percentage for 22 different traffic scenes in which different targets (e.g., traffic signs, bikes, cars) were present.
Figure 1: Example of stimulus material (In the upper picture the traffic sign is positioned at an expected location; In the lower picture at an unexpected location)
As is evident in Figure 2, visual search behavior is dependent upon the expectations induced by the environment. The lay-out of the environment activates a particular schema which induces expectations where to expect the target object. As is clear from this study, search behavior is biased towards those portions of the visual field where the target is expected. It should be realized that the effects of contextual driven search might be much stronger in real driving especially in conditions in which there is a relatively high visual load i.e., driving in busy traffic in urban environments, or under reduced sight conditions, for instance when driving in the dark or in twilight. Especially in these situations, rapid resource-inexpensive and conceptually-driven feature detection is advantageous. As is evident in Figure 2, objects at unexpected locations are not seen too late but, in most cases, not seen at all, i.e., when searching for objects at unexpected locations subjects tend to think that the target is not present. It is very likely that these type of errors also occur when searching during actual driving. In fact, accident data seem to confirm this notion: a large portion of drivers (about 37 %) involved in automobile crashes do not act too late but do not act at all to avoid the collision (Sussman, Bishop, Madnick, & Walter, 1985). In addition, Malaterre (1986) claims that 59% of all accidents are the result of inappropriate expectations or interpretations of the environment. Note that accidents do not occur often indicating that errors in visual sampling, i.e.,
detection misses, are not fed back to the driver. On the other hand, correct expectancies i.e., finding an object where you expected it, are consistently reinforced because the traffic environment is reasonably predictable.

Given these considerations, it is clear that extremely dangerous situations may occur when the design of the traffic environment induces certain expectations regarding the spatial arrangement of objects in that scene, which are not correct. The importance of inducing the correct expectations is supported by studies showing that visual selection does not so much depend upon the conspicuity of the target objects but more on the demands of the search task (Theeuwes, 1990, 1991a, 1991b). Conspicuous objects are not perceived when they are irrelevant for the task at hand. This suggests that when a traffic environment induces incorrect expectations, conspicuous signs and/or other infrastructural measures can hardly correct these expectations because they are simply not perceived.

Although there is no empirical evidence regarding the time frame of these expectations, it is likely that once expectations are set they cannot be changed easily. When initially the lay-out of a road indicates that it is a freeway, the driver will keep on interpreting the road as a freeway. Gradual changes to another type of road will lead to confusion and incorrect expectations. Consequently, the same type of road should connect a section which psychologically is interpreted as one: for example, a road connecting to cities, a road from a shopping to a residential area. Because people interpret a connecting road as a single psychological 'unit', it should be designed as such, that is, one type of road.

Self-Explaining Roads

Roads are self-explaining when they are in line with expectations of the road users. In the Netherlands, the design of freeways and woonerfs are to some extent self-explaining and inherently safe. On the other hand, a very large extent of the Dutch roads --for example the 80 km/h rural roads-- are not designed according to the safety principles mentioned above. These type of roads are not easily classified because they do not have any prototypical recognizable properties, nor do they compel the traffic behavior required on these roads. For example:
- The probability of the occurrence of slow traffic cannot be inferred from the road design.
- The probability of the occurrence of oncoming traffic is often unclear.
- The location and the presence of crossings and exits of driveways is not well marked.
- The estimation of the location and the required speed of curves is often difficult and inaccurate.

Figure 3 and 4 give some examples of the issues raised above.
Fig. 3: The probability of the occurrence of slow traffic cannot be inferred from the road design: Should you expect bicyclists on this road? (the answer is "yes").

Fig. 4: The probability of the occurrence of oncoming traffic is often unclear: Should you expect oncoming traffic? (the answer is "yes").
The use of consistent and easily understandable codes can to some extent reduce these problems. The design of roads should reflect the probability of encountering particular road users. Along the same line is the concept of 'Positive-Guidance' as developed by Alexander & Lunefeld (1986). They also suggest that the traffic situation should be in line with the expectations of the road users.

In addition to the development of a road which is self-explaining, is the development of a modern traffic control system which can add some 'intelligence' to the road environment. For example, navigation systems in the car with variable directional signs along the road can guide traffic, can reduce uncertainty in finding the optimal routes, and can remove instabilities (e.g., traffic jams) in the traffic flow. Variable speed advice dependent on the local circumstances (intensity, rains, fog) can optimize the traffic flow.

Research on categorization of traffic environments is scarce and the way schemata and scripts affect traffic behavior is for a large extent unknown. Yet, purely on theoretical grounds, it is possible to identify some criteria which will increase the self-explaining character of roads. When developing the 'road of the future' one should start with a few easy recognizable and distinguishable road categories. These types of roads should be designed in such a way that high speed differences and directional differences are not possible (Koornstra, 1991). Four categories can be distinguished: freeways, highways connecting larger regions, rural roads connecting residential and shopping areas, and woonerfs, i.e., roads going from door to door.

For these four categories, self-explaining roads should fulfill the following tentative criteria:

- Unique road elements (homogeneous within one category and different from all other categories).
- Unique behavior for a specific category (homogeneous within one category and different from all other categories).
- Unique behavior should be linked to unique road elements (e.g., woonerfs: obstacles-slow driving; freeway: smooth concrete-fast driving)
- The lay-out of crossings, road sections and curves should be linked uniquely with the particular road category (e.g., a crossing on a highway should physically and behaviorally be completely different from crossing on a rural road).
- One should choose road categories with are behaviorally relevant.
- The same road category should connect a section which psychologically is interpreted as a single unit (e.g., a road connecting two cities).
- There should be no fast transitions going from one road category to the next.
- When there is a transition in road category, the change should be
marked clearly (e.g., rumble strips)
- When teaching the different road categories, one should not only teach the name but also the behavior required for that type of road.
- Category-defining properties should be also visible at night.
- The road design should expel speed differences and differences in direction of movement.
- Road elements, marking and signing should fulfil the standard visibility criteria.
- Traffic control systems should be uniquely linked to specific categories (e.g., on freeways, systems that regulate traffic flow and on rural road, systems that restrict driving speed)

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METHOD OF IN-CAR OBSERVATION FOR THE EVALUATION OF ACCIDENT RISKS

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At the Highway Engineering Department of Gdansk Technical University behavioural techniques in the safety research have been undertaken. One of them is in-car observation of a driver's behaviours (manoeuvres, braking, steering, speed, pulse rate) and road-traffic conditions. Behavioural data have been used in close association with the accident data in order to estimate the accident risk caused by geometry and environment features. In the paper the data collection system, methodological problems and preliminary results are presented.

Introduction

The driver fulfils a specially important role in the road traffic process thus the study of his behaviour should also be treated with a special attention. The knowledge of influence of the road, his equipment and surrounding on driver's reactions is really necessary in traffic engineer activity to improve the traffic safety. Using of a test-car equipped in the traffic parameter recorders is very often the only one way to investigate drivers' behaviors in function of real traffic and road conditions.

From the psychological point of view, the driving process is very complicated one. Psychology is very often questioned about the means by which one think to be able to inflect the driver behaviour towards greater safety: information campaigns, training, layout of the environment and driving conditions. In psychological studies, the stress is put on as the road environment influencing speed use (Barjonet and Saad, 1987).

Driver's behaviour models are unfortunately not very well developed. There are several general outlines of a more descriptive character and very few of existing models have a predictive capacity that could lead to hypotheses which are possible to test empirically (Rumar, 1992).
In several research centers investigations on the perception process (Dore, 1991), risk models (Saad, 1988; Haight, 1986), psychological and sociological theories of the driver’s behaviours (Barjonet, 1988), are being continued. While if we consider this problem from the traffic engineering point of view, to appreciate a road in regard of geometrical features, homogeneity, comfort of driving and finally — traffic safety, the simple indicators, measures and characteristics of the traffic process are demanded.

Since 1976 in Technical University of Gdansk investigations on qualitative and quantitative measures of road traffic conditions have been carried out using a test-car. In 1986 we have improved the test-car making it possible to record, while driving, psychophisiological reactions of driver. We have started a research with the aim of:

- elaboration of a feasibility study to define the utility of test-car and driver psychophisiological reactions to the risk analysis,
- describing the relationship between road features as well as his environment and reactions of driver,
- initiation of scientific interrelations between traffic engineers, psychologists and sociologists, working in the domain of traffic safety.

The first stage of investigation, some results of which has been presented in this paper, concerned most of all the methodology of the field study, the choice of parameters of drivers’ and road-traffic conditions to be recorded, and the method of result analysis.

Data collection system

An instrumented vehicle and data collection system were developed specially for a series of experiments designed to investigate the effect of road and traffic features on speed changes, psychophisiological reactions of drivers and fuel consumption. The data-logger of this system is able to record simultaneously on the time base road features, drivers’ actions, drivers’ reactions and events codes from built-in 16 column printer (Fig. 1). The system operates at normal travel speeds with one observer and videorecorder to record operational features and visibility conditions. The sets of data contain the measured parameters.
Fig. 1 Data Collection System

in function of time every 0.5 sec, as well as a total comparison of general indicators of chosen sections:
- journey speed and time of journey,
- number and time of stops,
- delays,
- acceleration noise,
- gradient of speed,
- average and relative rate of pulse.
Up to now we have used this system to investigate:
- the road element homogeneity as a parameter for the evaluation of traffic safety,
- the effect road-traffic conditions on speeds, psychophisiological reactions and accident rates,
- objective and subjective risks problems; psychophisiological reactions as a intermediate measure of subjective risks.

Preliminary results of the experiment

The primary objective of road homogeneity research was to identify geometrical inconsistencies though the analysis of speed profiles for free-flow conditions and the investigation of relationships between running speed and horizontal alignment of two-lane roads. Geometrical inconsistencies were defined as changes in the highway alignment which are not in accordance with the drivers' anticipation. In many cases the average curvature proved to be the most significant geometric feature in the prediction of running speed and speed changes along the road. Also the speed gradient being a ratio of acceleration noise and average speed proved good quality standards (Fig. 2).

Fig. 2 Speed Gradient versus Average Curvature of Road
For urban roads, there is a significant connection of speed gradient and accident rates (Fig. 3).

![Fig. 3 Accident Rate versus Speed Gradient](image)

A study of literature concerned the behavioural investigation have shown that the procedure of surveys of driver's relation while driving was often used (Helander, 1975; Lobanow, 1980; Janssen, 1987; Kapusta, 1922). Nevertheless each approach to the scientific experiment was very well conditioned by the purpose and local features of drivers and road infrastructure.

To make a preliminary investigations of relationships between speed, psychophysiological reactions, road characteristics and accident data, an in-car observations on roads with different types of cross-sections have been carried out. Ten to twelve test-journeys were done on each road section by seven drivers being 28-48 years of age. The comparison of results shows at first significant different values of speed and pulse rate for rural and urban roads, and for two-lane and four-lane roads (Fig. 4). Also, for investigated road sections we found an increase the
Fig. 4 Comparison of Values for Different Cross-sections

relative pulse rate on road sections with higher accident rate (Fig. 5).
Basing on an assumption of Wright (1986) that the probability of an accident occurrence is connected to the relationship between subjective and objective risks we have
started a research concerning to individual driver. Assuming that rising of the risk in a road-traffic situation causes an acceleration of the psychophisiological process (Naatanen and Sumala, 1976) the pulse rate of driver had been taken into consideration as an indicator of subjective risks level. In this study results of our research on different elements of two-lane roads for the calculation of safety margin and traffic conflicts parameters will be used.

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Titel:

DYNAMIC ASPECTS OF MOTORWAY TRAFFIC SAFETY

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Abstract

In a current research program at the Delft University of Technology and the Institute for Road Safety Research SWOV we are developing an adaptive control strategy for the motorway system. The purpose of the system is to optimize traffic flow under safe conditions. This paper describes how safety is incorporated into the system.

The central focus is on traffic behaviour. Traffic data derived from detection loops in the road surface form the basis for a quantitative description of the traffic situation. These data are compared to a traffic reference model which interprets the safety of the situation on the basis of a set of safety criteria. On the basis of this interpretation action may be taken to change traffic flow conditions, by reducing speed or by increasing following distances between vehicles.

The safety criteria are a result of extensive research, combining several methods, including video analysis, expert opinion research and measurement of mental load of drivers. The paper briefly describes these methods and shows that, although qualitative interpretations of traffic safety are easy to generate, quantification of traffic safety characteristics takes time.

1. Background

Traffic is growing continuously. A traffic growth is expected of at least forty percent in the next twenty years. The present road capacity will not be sufficient to comply with the demand of traffic. This will lead to an increasing number of traffic jams. At the same time developments like industrial Just-In-Time management systems increasingly demand a traffic system in which reliable predictions about travel time can be made.

The cost traffic accidents cause to society are very high (in the Netherlands approximately 1300 deaths a year, total economic costs of traffic accidents are estimated at eight billion guilders a year). Government targets have been set to try to reduce traffic casualties with 25% in the year 2000, compared to 1985.

The situation mentioned above has led to an emphasis on the development of sustainable safe traffic systems. On motorways there has been a change in the approach to traffic flows: The traffic will have to be controlled instead of being merely monitored. Electronic systems will be needed to help with measuring traffic and informing the driver on desired behaviour.

A current research program at the Delft University of Technology and the Institute for Road Safety Research SWOV is developing an adaptive control strategy for the motorway system. The purpose of the system is to provide a maximum traffic flow on a motorway network under safe conditions. The system is based on a hierarchical approach. This model consists of three layers (see fig 1). The first layer makes a long term prediction of traffic density in the
complete motorway network. This can be used as a basis for route guidance and radio traffic information, and slow adaptation of the lower layers.

Figure 1. Diagram of the control strategy

The second layer consists of a number of subsystems. Each subsystem coordinates the traffic management in a specific part of the net, a stretch of road containing a limited number of junctions. Each subsystem communicates with the adjacent sectors to take the traffic up- and down-stream into consideration, in order to provide short term coordination. If necessary, a separate coordinator may provide coordination between non-adjacent subsystems.

The purpose of the third layer in the model is to preserve traffic safety. While the traffic controller tries to optimize traffic flow, the safety module must ensure safe traffic conditions. For every local traffic controller in the second layer, there is a safety module.
This module can be divided into two parts (see fig 2). The diagnostic part compares the actual traffic situation to a reference model of the traffic and imposes conditions on the second layer for dealing safely with the traffic. The feedback part provides information to the road user, to induce safe behaviour. This information must be attuned to the road users’ capabilities through the use of proper semantics, placing and timing of the messages. The system uses traffic information that is primarily generated by detection loops in the road. These detection loops keep track of every passing vehicle and provide an estimate of the speed and length of each vehicle. All three layers are based on the same information, although the first layer uses more aggregate data, while the second and third layer use the individual data. This paper is concerned with the third layer, the safety module. The focus of the paper is on the development of a traffic reference model. We will set the requirements for this model in the second chapter. The model will have to combine quantitative and qualitative aspects of the traffic. This requires a special methodology. The methods used will be described in chapter three. In the final chapter some conclusions will be drawn.

2. Requirements for the traffic reference model

In current traffic control models the consideration of the human factor is reduced to a minimum. These macroscopic models simplify human behaviour to a stochastic influence, with no consideration for the complexity of the behaviour or the possibilities to influence it. This approach has led to the presently used system on the Dutch motorways. This system is used for Automatic Incident Detection (AID). AID reacts to hazardous situations on the road once the system recognizes them. Usually the system reacts when speed drops below a fixed point. It then alerts drivers with matrix signs, signalling advised speed. (The system in the Netherlands shows a 70 Km/h sign when the speed on the subsequent sector of the motorway drops below 63 Km/h and a 50 Km/h sign when the speed drops below 42 Km/h.). The AID system has proved itself in the past 15 years. There has been a considerable reduction in head-tail collisions. But neither the speed limits of 42 and 63 km/h nor the messages on the matrix signs are based on any kind of theory. They have been established by trial and error. The system cannot anticipate the traffic situation, but can only react to it. The system we are
working on in this project is supposed to be able to determine when a situation will become dangerous, and react to that before it actually happens. In this way we hope to be able to prevent accidents and increase the dynamic capacity of the road by avoiding or at least postponing traffic jams.

An important addition this research can offer to traffic management is a closer look into what is considered to be the black box in traffic management: the driver. Linear individual models of traffic behaviour are not sufficient to describe the traffic process. Furthermore they give no clue as to what sort of method could be used to influence behaviour. Psychologically oriented traffic research puts the emphasis on the individual road user. This results in a driver model. Although the behaviour of other road users is taken into account, for instance in research on following behaviour, it is hard to utilise the microscopic driver models at a higher aggregation level, where a judgement about the safety of the traffic process must be made.

The traffic reference model we are developing at the moment is a mesoscopic model. The central focus is on the traffic process itself, i.e. the interaction between road users. To be able to make predictions about safety we need to model the dynamic characteristics of the traffic stream, and at the same time account for the behaviour of the drivers that make up the traffic stream.

Our traffic reference model also needs to be quantitative. The detection loops that provide the input for the model generate the speed and length of each passing vehicle. With these basic parameters we try to make a quantitative description of the current traffic situation. When the traffic situation up- and downstream is taken into consideration as well, it is possible to make a prediction about what will happen in the near future. This description still does not provide us with a measurement of safety, or a guideline for interference in the traffic flow. There has to be a translation of the actual traffic state to a judgement about safety. In a number of experiments we have used video observation to obtain a qualitative interpretation of the safety of the traffic. The quantification of these qualitative judgements will enable us to create our traffic reference model.

3. Methodology

3.1 Introduction

The purpose of this research project is to develop the traffic reference model mentioned in the previous chapter. The model has both quantitative and qualitative aspects. In this paper the quantitative detection loop data analysis and the video analysis are discussed separately. In practice the two methods are developed simultaneously.

Beside quantitative detection loop data analysis and video analysis two other methods are used to enlarge understanding of the traffic process. Mental load research is widely used in operator tasks. In our project we use mental load as an approach for failure in perception, decision or action. Finally linear network models, for instance neural network models are used to model the traffic process.

In our system development process we distinguish several stages:
- Defining the problem
- Choosing and developing methods
- Modelling, defining dependencies
- Verification of the model
- Implementation

At present we are in the middle of the modelling process. Once the criteria have been defined we intend to verify the model by means of an evaluation study of traffic accidents. These
accidents will have to be well documented. Because the accident analysis will need to
generate the kind of data our programs use. We want to investigate if the limits we have set
in our model were exceeded when the accidents occurred. A project suitable for our purposes
could be the accident analyses that will take place in the evaluation study of the new fog
detection system near the town of Breda. Here detection loop data are being collected on a
daily basis. Another verification of the model could come from simulator studies.
This paper will discuss only the methods that have been used so far.

3.2 Detection loop data interpretation

The data
Detection loops in the road surface generate the traffic data that are used. These loops are
placed over large distances (about 200 km.) of the Dutch motorway system. The microscopic
data we are using for our traffic description are collected on a small scale for research
purposes only. For our research we have used a fixed set of data. These data were collected
on the A13-west between The Hague and Rotterdam, on a stretch of eight kilometres data at
500 m. intervals. All three lanes and exit and entrance slipways were measured separately.
Of each passing vehicle the following data were registered:

- Exact time of passing (in ms)
- Speed (in 10^3 Km/h)
- Length (in 10^3 m)
- Lane

The data collection took place on one day, in august 1990, from 7:45 a.m. until 17:30 p.m.
This period runs from the morning rush hour up to and including the evening peak. At
approximately four o'clock a critical situation occurred and an accident happened.

The programs
Although the final model will have to work in real-time, the data have been processed off
line during the research phase of the project. In the past two years several programs have
been developed at the Safety Science Group and SWOV to permit a closer look at what
actually happens on the road. The detection loops show what takes place at a number of
points on the road, but give no information about what happens in between. This sets
limitations to the kind of information that can be extracted from the data. For example lateral
movements of cars can only be deduced indirectly, for instance from the total number of cars
per lane at successive cross-sections. Nevertheless the programs can determine a large
number of different characteristics of the traffic flow.

Traffic flow characteristics
Traffic flow is usually described in characteristics that have been used for decades:

- **Intensity** describes the cars that pass a specified point in a specified time, for
  instance 2300 cars/h.
- **Density** describes the number of cars on a section of the road, for instance 80
  cars/km.
- **Average Speed** is used to describe the speed of the traffic flow.

In our project we are looking for the variables that provide the best description of the traffic
flow. We have found that a better description of the traffic flow can be achieved if these
variables are replaced by derived variables

For instance the three variables described above can be replaced like this:
- **Production** (vehicle times length per second) instead of intensity. In production the length of a vehicle is weighted as well as the number of cars. This way we can account for trucks in the traffic (see fig 3).

- **Covering ratio** instead of density. Here too we use the length of vehicles. Long trucks take more space than passenger cars, leaving less maneouvring space on the road.

- **Weighted harmonically average speed** instead of average speed. The speed weighted with length accounts for the fact that longer vehicles, trucks and lorries, drive relatively slow. On the other hand speed of vehicles with a bigger mass have a larger effect on safety, because $E=MV^2$.

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**Figure 3.** Although the number of vehicles is the same, the bottom lanes are more crowded

Another addition to traffic flow description is the minimum deceleration vehicles need to apply to avoid contact the preceding vehicle. Drivers tend to keep the minimum deceleration below $1 \text{ m/s}^2$. This is the deceleration they can achieve without braking. When the minimum deceleration rises above this limit this may be an indication of dangerousness.

The question remains which characteristics are important in determining the safety of the traffic flow. To answer this question we have used other methods, in addition to the quantitative analysis of the detection loop data. We will go into those methods in the next section.
3.3 Video analysis

Introduction
We have used video observation to obtain a qualitative interpretation of the safety of the traffic on the motorway [Bangert, 1992]. In a series of experiments we have used the opinions of experts to find a set of criteria that would enable us to define whether a specific traffic situation is safe or not. The persons who participated in this project were considered experts in the field of traffic safety. They were chosen from different backgrounds: Traffic police, scientists with different backgrounds and experienced drivers.

In this part of the research we were interested in how an evaluation of a specific traffic situation is made. What are the criteria experts use in forming an opinion about the safety of the traffic?

Methodology
The video fragments used in our experiments were recorded on the same day that the detection loop data were collected. The recordings show the same motorway, the A13-west. The tapes show a part of the motorway (see fig 4).

Figure 4. A13 west. Video cameras cover about 300 m. up- and downstream.
The video was recorded from a fly-over at a height of five meters. Both up-stream and down-stream video tapes were made. The accident that occurred around four o'clock cannot be seen on the video tapes. The circumstances that led to the accident, however, are shown on the tape. The driver of a van spotted the camera and braked, thinking it was a speed control camera. The cars driving behind this van were at such a close distance that they could
not reduce their speed in time to avoid an accident. Several times during the day cars had used their brakes in front of the camera, but only at about four o'clock did this result in an accident. Our experiment was designed to try to find out if the experts were able to determine this critical situation.

After four o'clock the video up-stream shows only a traffic jam, while the video down-stream shows the traffic that has just passed the head of the jam and is trying to gain speed again.

In a series of experiments, fragments of these video tapes were shown to the experts. They had to judge the safety of the traffic in a number of frames. In the experiments these fragments had variable length. Other differences between the experiments related to:

- Comparison of video fragments in pairs versus showing of one long video fragment
- Structured experiments versus general discussion about the fragments
- Random fragments versus fragments selected on one criterion, for instance truck overtaking manoeuvres
- Experts interviewed in a group or individually
- Upstream fragments versus downstream fragments

Apart from the video experiments we also used interviews held at a point where traffic could be observed. One of these interviews took place on a point with an overview of the road, the others took place within an inconspicuous police car, surveilling the motorway. In these interviews the experts could point to situations in the traffic around them that they considered important for evaluating traffic safety.

Traffic safety characteristics

The safety of a traffic situation is determined by a combination of factors. Some of these relate to events, some to characteristics of the traffic stream. The events the experts mentioned in the experiments include trucks overtaking, cars driving in the wrong lane and abrupt manoeuvring. Events are dangerous only in a specific context. We are trying to model this context for our traffic reference model.

The same question was asked through all the experiments: When are these events considered dangerous? The experts can indicate a number of traffic characteristics that influence safety. These include heavy traffic, close following distances, lane changing, unexpected and complex traffic situations. The experts find it hard to point out the exact value of a variable when it changes from being safe to dangerous.

The point of view of the camera influences traffic safety judgements. A fine example of this is trucks overtaking. When the camera is pointed upstream, an overtaking truck is seen as a bottleneck for the traffic upstream. A video fragment of downstream traffic shows the truck blocking the view of the upcoming traffic. In both cases truck overtaking is considered unsafe. Although the result is the same, the underlying reasoning is different.

Conclusions

Although some of the experiments have yet to be completed, a number of conclusions can be drawn.

1. There is a large consistency between the experts from different backgrounds in their judgement about the safety of the situations. There is however a difference in the criteria the different experts use to form their judgement.
2. The experts can indicate very well dimensions that can be used to judge safety, but they are unable and unwilling to give exact criteria to determine at what point a dimension reaches a dangerous value.
3. Subjects are inclined to base their judgement on events, rather than on changes in the traffic flow.
Each of the methods used individually has its disadvantages. However, when they are used together, they can complement one another. The experts focus on different aspects of the traffic in different experimental settings. Because of this they have a chance to emphasize different aspects of the traffic behaviour.

### 3.3 Mental load

**Introduction**

Another methodology we want to apply to determine whether a traffic situation is safe or not, is to investigate the mental load of drivers in different traffic situations. Research into mental load is widely used where an operator has to fulfil one or more tasks, which require a lot of mental effort. The task demands on drivers on the motorway are usually low. However, considerable task demands are also possible here.

There is another phenomenon we would like to investigate. Driver models describing motorway traffic behaviour distinguish between two types of driver control. In light traffic the driver can anticipate the behaviour of other drivers and act accordingly. This is called anticipatory control. In heavy traffic, with short following distances, the driver can only react to the car in front. This is called pursuit control. Determining at what moment drivers change from one mode of control to another may help us understand traffic behaviour and its relation to safety.

In mental load research different approaches are possible. In our project two methods are being used. Since not all the experiments have been finished yet, only the ideas and methods can be discussed here. The results will be published later.

#### Method 1

Secondary tasks have been used in experiments that have been carried out by TNO-IZF for a number of years [Verwey, 1989]. In secondary task experiments the subjects' performance on a controlled second task is interpreted as an indicator of task demands on the primary task, the driving task. When the primary task requires a lot of attention, the performance on the secondary task will be decreased. The performance on the secondary task indicates if a driver is able to receive and process information. When task load is too high, the chances are that the driver will not notice extra information that is supplied by traffic management systems. This kind of research can help us in determining the right moment to present information to the driver about the traffic situation ahead or about the kind of behaviour that is required from him.

#### Method 2

The measurement of heart rates is a frequently used method in mental load research. In particular the $10^{-1}$ Hz variability in the heart rate is thought to represent mental load. One of the great advantages of this method compared with the secondary task method is the fact that it is non obtrusive: the experiment does not interfere with the driving task itself. In a current study (to appear in 1993) van der Linde is evaluating the use of this method for motorway traffic research. In this study the question under research is whether the intensity of the traffic influences the mental load of the drivers. The research is being carried out with the help of the Road Traffic Research Centre in Groningen.
Conclusion
As far as we can assess, the effect of different aspects of the dynamic traffic environment on mental load have not been studied before. This is partly because it is generally believed that dynamic traffic characteristics only have a small effect on mental load. On the other hand it is also because up till now the dynamic environment could not be controlled, not even retrospectively. Detection loop data open a new field for mental load research, but there are a number of drawbacks when using mental load methods for determining traffic safety.
- There are as yet no standards concerning the amount of mental load that is desirable. Underload and overload are also not defined independently. It is therefore hard to relate mental load to safe or dangerous traffic situations.
- There are no standards to determine which method of measuring mental load should be used for a specific task. The choice of a method sometimes seems to depend more on the theoretical model used by the researcher than on the task.
- Mental load varies considerably between subjects. It can also vary considerably for subjects performing the same task on different occasions. The mental load is very sensitive to disturbances. This implies that thorough research requires the use of a lot of subjects and a lot of tests, which makes this kind of research relatively expensive.
- Mental load research can be very useful when the link between mental load and the risk of failures in perception and action can be established. This criterion has an immediate value for our research project.

Despite the disadvantages, mental load research can add valuable knowledge to traffic safety research, once standards have been developed.

3.4 Linear network models
Linear network models are used to determine if a traffic stream behaves as expected. These models predict traffic flow, on basis of simplified models of individual behaviour. Individual differences are reduced to a stochastic variable. With these models a description is made of traffic stream behaviour. A simple model would be the prediction that every vehicle will keep its speed and lane. Detector loop data are used as input. The output of the model is a prediction for every vehicle that will pass the next detector loop. The output of the model is compared to the data from the next detector loop. Usually the simple model is a good predictor of the traffic flow. Small deviations can be expected, but large deviations between the predicted behaviour and the actual traffic behaviour can be considered as a change in the traffic situation. These deviations can be caused by disturbances in the traffic flow. The size of the deviation may be an indication of the size of the disturbance of the traffic flow.
Linear network models are an easy way of modelling traffic behaviour. They can be quickly implemented. Instead of linear models a neural network can be used to make an estimation of the development of the traffic stream. A neural network can be taught the behaviour of the "normal" flow of the traffic. Again deviations in expected behaviour and measured behaviour can be an indication that traffic has become out of the ordinary. When enough data have been collected and learned by the network, it may also be able to recognize traffic situations that have in the past led to a traffic jam or accident.

4. Conclusions
Very little research has been directed to the mesoscopic level of interaction between drivers that forms the traffic process on motorways. This is partly a consequence of the fact that dynamic vehicle interaction is difficult to capture without advanced technology such as
detection loops. Video can be an aid in this respect, but can not take the place of the
detection loops. Another reason for this relative neglect could be that this type of research
does not fit into the established scientific disciplines that are concerned with traffic research.
However, this research is necessary if we want to control traffic flow and driver behaviour.
In our project we used a number of methods simultaneously. The methods mentioned in the
methodology section have at present not led to a definitive model to describe the safety of
motorway traffic in real-time. However, the indications so far are positive. We have studied
the traffic process by using techniques that are fundamentally different from previous
research. Although our research has not yet been completed, we can already draw a number
of preliminary conclusions.

Our expert opinion research has shown that the qualitative judgement of motorway traffic
safety is coherent between experts. The constructs experts use in defining safety can be
translated into a limited set of qualitative dimensions. Concepts from the field of civil
engineering can be translated into the vocabulary of traffic psychology and vice versa.
Quantification of these dimensions seems difficult, but possible.

Quantitative analysis of the detector loop data shows that description of traffic in meaningful,
safety related dimensions is possible. Microscopic traffic data provide an insight into the
traffic process that can never be obtained simply from aggregated data.
The model for motorway traffic safety will be based on a limited number of dimensions. At
this moment we are making a quantification of the qualitative dimensions found earlier. This
will lead to a traffic model that can be used as a reference for our system as mentioned
above.

The point of view towards traffic that is used in our research project, requires an
interdisciplinary approach. The project combines methods from a number of disciplines
involved in traffic research. Communication between the different approaches, and translation
of the results of one approach into another, is the best way to converge towards a solution to
this multi-dimensional problem. Besides solving the problem of the mesoscopic traffic model,
this project can also help to bring the different views that often seem wide apart closer
together.

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A SUSTAINABLY SAFE ROAD INFRASTRUCTURE:
THE START OF THE REALISATION

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Abstract

The accident rate figures for the Netherlands show that accomplishing the task of traffic safety necessitates a change of course. It is our aim to create a sustainably safe road infrastructure. Therefore it is crucial to realize that accidents happen as a result from situations in which two factors meet: the one is speed and the second convergence of traffic. This will lead to the following concept: an environment that consistently and sharply reduces speeds at all clearly recognizable points of convergence, such as crossings and junctions. This can be done by means of modern small roundabouts, speed bumps and go-slow bends. If these methods lead to a reduction of the road speed below the level normally expected on that particular type of road, this concept will lead to a reduction of the number of points of convergence by discontinuing intersections. Subsequently the hierarchical function of roads in traffic structures will be strongly determined by the distances between intersections.

What matters now is to gain wide acceptance among politicians for such an approach and thus for traffic measures that will lead to a further differentiation of accessibility. The result of the implementation would be that on short distances have to slow down almost to the speed of cyclists. On longer distances this will only be the case during the first and the last part of the trip.
With respect to new infrastructures people have been slowly getting used to this idea. The reconstruction of existing connections, however, is new to them. Against this background, the Province of South Holland has chosen an approach, in which alternatives are developed for a number of trial projects in order to test the practical applicability of this concept.

1. Introduction

Road traffic takes a heavy toll annually in terms of casualties. In 1991, 1300 people were killed in traffic accidents in the Netherlands, and according to the records 47,300 people were injured. In the Province of South Holland alone, 169 persons died as a result of traffic accidents in that year, while 9928 cases of injury to traffic accident victims were reported. The provincial government operates a portion of the total road system, notably interurban roads linking up centres with a certain minimum of facilities. The length of those roads totals 465 km. Altogether, the annual
volume of traffic was 1.73 milliards of vehicle kilometres. In 1991, 35 people were killed on those roads and the number of people injured totalled 820. In comparison to 1989 and 1990, the traffic toll has decreased. That holds true for the Netherlands, for the Province of South Holland and also for the provincial roads. Viewed in relation to the period from 1985, the picture is more obscure. Fortunately, the number of fatalities can be reported as decreasing, whereas the number of people injured seems to be levelling off.

If this trend continues at the same rate, it will mean that the national target regarding traffic safety policy cannot be reached. This target is '25 percent fewer traffic victims in the year 2000 than in 1985'. The Province of South Holland has also adopted this target [1]. For the long term, an even more ambitious target has been set. In 2010, the central government aims to have reduced the number of people killed by 50 percent in comparison with 1986. Similarly, the number of people injured must be reduced, by 40 percent. It looks as if the Province of South Holland will also adopt this last policy [2].

In order to reach this goal, three spearheads of new policy were opted for in 1991:
1. Safety on roads with a speed limit of 80 kilometres an hour;
2. Safety of bicycle and moped traffic;
3. Tackling hazardous spots more rigorously.

On the basis of these premises a plan of action was developed. to begin with, the emphasis was put on the following issues:
a. Starting trial projects aimed at enforcing a speed limit of 80 kilometres an hour
b. Tackling black spots and locations with high concentrations of cycling accidents
c. Participation in regional projects intended to make people more road-safety conscious

The first issue has been chosen, because research suggests that enforcing the (legal) speed limit on the 80 km/h roads will lead to a reduction of 25 to 50 percent in the number of fatal accidents. At the same time, the number of accidents resulting in injuries would fall by an estimated 20 to 40 percent.

Issue b. addresses problem areas expected to become much safer as a result of improvements to the traffic infrastructure.

Issue c. reflects the importance attached to an on-going mobilisation of public opinion. Despite all the progress made, the price in human suffering exacted by traffic accidents is very high indeed, compared to the risk linked to similar transport activities.
2. A new approach

Several publications have recently stressed that a change of course is necessary in order to pursue an effective traffic-safety policy. We must guarantee safety, rather than fight lack of safety. This is why terms, such as 'Sustainably Safe Traffic' [3] and 'Sustainably Road Safety Infrastructure' [4] are introduced.

Experts on road safety can learn a great deal from the approach applied to other forms of transport such as shipping, air traffic and rail transport. In those areas, safety is an integral part of the design process, in which potential risk factors are systematically eliminated as far as is possible. Such an approach has rendered other modes of transport safer than road traffic [5], as shown in table 1.

Table 1. Risks per mode of transport in 1990 for several degrees of exposure.

<table>
<thead>
<tr>
<th>Fatal risks</th>
<th>Per 1 milliard vehicle km's</th>
<th>Per 1 milliard person km's</th>
<th>Per 1 million person hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road traffic Neth.</td>
<td>15</td>
<td>11</td>
<td>0,4</td>
</tr>
<tr>
<td>Rail transport Western Europe</td>
<td>1,1</td>
<td>0,16</td>
<td>0,01</td>
</tr>
<tr>
<td>Sea corridors Japan</td>
<td>6</td>
<td>not applicable</td>
<td>not applicable</td>
</tr>
<tr>
<td>Air traffic USA</td>
<td>0,7</td>
<td>0,04</td>
<td>0,2</td>
</tr>
</tbody>
</table>

Against this background, the factors ultimately determining the safety of the road infrastructure must be thoroughly understood. A run-down of the risk of injuries linked to the various types of roads can be useful (see table 2).

Table 2. Risks of injuries linked to the various types of roads in the Netherlands and the roads controlled by the Province of South Holland.

<table>
<thead>
<tr>
<th>Types of road resulting in</th>
<th>Speed limit in km/h</th>
<th>Number of accidents resulting in casualties per million vehicle kms</th>
</tr>
</thead>
<tbody>
<tr>
<td>well designed residential go slow area</td>
<td>30</td>
<td>0,04</td>
</tr>
<tr>
<td>common residential go slow areas and streets in 30 km/h zones</td>
<td>30</td>
<td>0,20</td>
</tr>
<tr>
<td>residential street</td>
<td>50</td>
<td>0,75</td>
</tr>
<tr>
<td>urban traffic thoroughfare</td>
<td>50</td>
<td>1,33</td>
</tr>
<tr>
<td>roads in the country</td>
<td>80</td>
<td>0,64</td>
</tr>
<tr>
<td>non urban roads closed to slow traffic</td>
<td>80</td>
<td>0,30</td>
</tr>
<tr>
<td>(roads controlled by the province of S.H.)</td>
<td>(80)</td>
<td>(0,38)</td>
</tr>
<tr>
<td>motorways</td>
<td>100</td>
<td>0,11</td>
</tr>
<tr>
<td>motorways with fly-overs</td>
<td>100/120</td>
<td>0,07</td>
</tr>
</tbody>
</table>

The table shows that a well designed residential go-slow area is safest and that a motorway is also relatively safe. The road categories between the residential go-slow areas
and the motorways prove to be the main problem: urban thoroughfares are 30 times more dangerous than well-designed residential go-slow areas. Moreover, in South Holland, the risk is 5 times greater on provincial roads with an 80 km/h speed limit than on motorways.

The figures relating to the motorways and the residential go-slow areas clearly demonstrate that a consistent approach to traffic safety problems is effective. Thus, setting a more ambitious target should not be dismissed as unrealistic. In the publication 'Everyone knows someone...", the SWOV states that the traffic risks would be reduced by 50 percent, if all roads met the safety standards of the motorways and the zones with a speed limit of 30 km/h. But reaching those goals will depend on the political choices made.

3. Sustainably safe provincial roads: which matters require our attention?

In the foregoing, it has been pointed out that both the go-slow areas and the motorways are safer. This is obvious, if one considers that accidents are the result of the combination of convergence and speed.

On motorways, speeds are high but the potential collision factor is low. In go-slow areas the situation is the other way round. Both will result in a safer situation. These facts are the key ingredients of a sustainably safe road infrastructure.

Basically, the following formula can be applied:
Chart all potential points of convergence and opt consistently for one of two possibilities:
Either remove the point of convergence or reduce speeds to approximately 20 to 30 km/h at that particular point.

The beauty of this approach is not only its simplicity. It can be the basis for a way of thinking about the hierarchy of roads within traffic structures. After all, if each point of convergence results in bringing down speed to about 25 km/h, determining the functional speed of a road in a certain hierarchy will influence the choice of distances between intersections of different types of roads. In the end, such an approach would also point the way to proceed regarding the standardisation of road features as advocated by the SWOV and others.

This approach cannot, of course, be more than a frame of reference, since an over-simplified application of it would go awry immediately, given the diversity of our road network. However, it appears to be worth our while to test this concept further by practical experience, in order to reach a sustainably traffic safe road infrastructure.
4. Rationalisation of the sustainably safety model with the accident figures on provincial roads.

In order to see what the application of the aforementioned concept for sustainably traffic safety would mean in reality, the accidents occurring on provincial roads in the period from 1987 to 1990 have been analyzed more closely. This leads us to the following conclusions:

- 58% of accidents happen at junctions;
- 5% of accidents happen at or near exits;
- 37% of accidents happen elsewhere between junctions.

This means that the majority of accidents indeed occur at points of convergence that are immediately recognizable as such. Also, 37% of accidents happen at locations that are not instantly recognizable as potentially hazardous. Regarding this category, we can expect substantial benefits from enforcing the (legal) speed limits.

5. Implementation of the permanent safety model within the context of the provincial policy.

Clearly, the governmental targets regarding the reduction of the number of accidents require a more stringent traffic safety policy. Given the results achieved in other sectors of the safety policy, an approach, with safety consciousness playing an integral part, offers good prospects. Therefore, South Holland intends to try out this model on four roads in order to evaluate the practical consequences. The following questions arise:

- What distances between roundabouts on provincial roads in rural areas are feasible? Will the implementation of an average standard distance be a practical concept? Or, taking the functional length of the road\(^1\), is the use of an average standard speed\(^2\) a better approach?

- Is there enough political and social support for principle of linking secondary roads to a parallel road instead of to the main road, if those secondary roads do not qualify for a connection via a roundabout?

- Is it possible to consistently put up speed-reducing constructions, such as go-slow bends or speed bumps, at the discontinued junctions of parallel roads?

These questions point towards a dilemma which crops up when

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\(^1\) The functional length of a provincial road means the distance between two centres via that road. This determines whether this connection is considered a provincial road.

\(^2\) Standard road speed is the average speed feasible on the road, including the crossings, on the basis of its function at times when there is a free traffic flow.
we start applying the concept of an inherent safety road system. The model as such excludes a combination of convergence and speed. But this rule clashes with the endeavour to maximalize the accessibility which usually requires that very same combination. The only way to solve the problem is to make a new, adequate functional classification of the road system.

In this context, bearing in mind the accessibility versus safety dilemma, for provincial roads the basic question must be: what distance between roundabouts is feasible. The more roundabouts, the less social acceptance there will be, for a too large number of them has decidedly negative effects. In the first place the overall speed will be diminished, causing a decrease in accessibility. Secondly, and more importantly, the drivers will get irritated and may start acting dangerously. In order to find an answer to the first question, we analysed the relation between route speed on the one hand and the distance between roundabouts on the other hand. The results are shown in figure 1.

As might be expected, the smaller the distance between roundabouts, the more route speed decreased. Now, on provincial roads the following speed standards are recommended (also depending on the different longitudes of
drives on provincial roads and the quality of minor roads):
in rural areas - 70 to 75 km/hour,
in urban areas - 60 to 65 km/hour,
indicating the recommendation for setting a minimum to the
average distance between roundabouts:
in rural areas - 2 to 4.5 km,
in urban areas - 1 to 1.5 km.

These standards indicate that the ideal minimum distance
between roundabouts is 2 to 4.5 kilometers in rural areas
and 1 to 1.5 kilometers in urban areas.

The best way to confront the remaining difficulties is to
map out the several possibilities and to see to what extent
the approach is at all practicable. Undoubtedly, many
compromises will prove to be necessary in the face of
reality. But a further analysis should enable us to
translate these compromises into alternative solutions. For
in each case it can be made clear what the traffic-safety
consequences are for the different political choices.

6. Example of a specific case

To measure the effects of removing junctions on provincial
roads, we calculated a specific case. It concerns a village
with 15,000 inhabitants. There are three junctions at that
particular road with a distance of 2,100 m and 600 m
respectively (see figure 2 below).
The computation of the effects is based on the assumption of a linear relation between the accidents and the intensity of traffic. Our first question is what happens if only the central junction at the provincial road is eliminated. It turns out that the total amount of accidents in the area as a whole will increase. But at the same time the number of accidents with personal injury will perceptibly diminish (figure 3: variant A).

**EXPECTED EFFECTS OF SECURITY MEASURES VARIANT A**

<table>
<thead>
<tr>
<th>Variant</th>
<th>Variant O: present situation</th>
<th>Variant A: withdrawal of the central connection</th>
<th>Variant A - Variant O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of accidents</td>
<td>82</td>
<td>90</td>
<td>+ 8</td>
</tr>
<tr>
<td>Injury accidents</td>
<td>15</td>
<td>12</td>
<td>- 3</td>
</tr>
</tbody>
</table>
Figure 4 (variant C) shows an alternative in which not only the [central] junction is removed, but the two [other] normal intersections have been replaced by roundabouts. The result is that both the total amount of accidents and the number of accidents with personal injury are lower.

EXPECTED EFFECTS OF SECURITY MEASURES VARIANT C

<table>
<thead>
<tr>
<th>Variant</th>
<th>Variant O: present situation</th>
<th>Variant C: - withdrawal of the central connection - construction of 2 roundabouts</th>
<th>Variant O - Variant C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of accidents</td>
<td>82</td>
<td>63</td>
<td>- 19</td>
</tr>
<tr>
<td>Injury accidents</td>
<td>15</td>
<td>7</td>
<td>- 8</td>
</tr>
</tbody>
</table>
It follows that in order to create a sustainably safe infrastructure also on minor roads speed should be reduced at intersections. One has to realize that the implementation of this rule causes problems. This is not due to technical or economical difficulties, but to social acceptance. People must be brought to regard safety as more important than unlimited accessibility. For the inevitable result of the implementation is that on short distances drivers have to slow down almost to the speed of cyclists. On longer distances this will only be the case during the first and the last part of the trip.

7. Parallel safety policy

Clearly, one cannot expect to eliminate all potential points of conflict on provincial roads, if only because 40% of cases occurs at points of conflict that are not recognizable as such. This is why it is advisable to combine such an approach with a reinforcement of the 80 km/h speed limit. To that end, the province has commenced a trial project. This project comprises a combination of theme signs and signs that light up when motorists exceed the speed limit, and at seven sites suitable for having speed checks and holding up cars in order to fine motorists, a radar camera will be permanently mounted at two of the seven sites.

The percentage of bookings for speeding is likely to be very low, if the level of law enforcement is high. That enables such an approach to be applied in a more general context. Although this will ultimately require more strenuous efforts by the police, the benefits should be substantial, especially, when the social cost of traffic casualties is taken into account. However, one cannot preclude that the costs of effective, mainly automatic speed checks will be completely covered by the proceeds of the speeding tickets, and having no financial barriers, tackling speeding more rigorously can be done without having to cut down on other police-tasks.

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THE EFFECT OF ENVIRONMENTAL AND DESIGN PARAMETERS ONTO SUBJECTIVE ROAD SAFETY - A CASE STUDY IN POLAND

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Abstract
In order to get a better insight into the safety effects of alternative road designs, the subjective safety experiment has been conducted. The experiment has been designed to test the effect of geometric design characteristics and road environment on subjective safety of rural road curves. The method used here allows to investigate the effect of real driving environment on safety in a complex way. The results have shown the importance of the composed effect of curve geometry and curve environment on subjective safety of rural curves.

Introduction
Road safety, especially in rural areas, is critically influenced by the way road is built. Although relationships between safety and road features are being studied for nearly 50 years, clearly much remains unknown about safety and geometric design relationships.
In most of safety related studies, accident rates associated with different roadway design have been estimated by using actual accident records and travel data. This approach, basing on accident research is difficult:
- accidents are relatively infrequent so that deep statistical studies require consistent data collected over long periods of time for many kilometers of road,
- many factors related to the road environment, the driver and the vehicle, interactively contribute to the occurrence of severity of accidents, but seldom included in the accident data base (even with reasonably complete data bases, researchers are often unable to sort out effects attributable to the specific roadway features),
- estimates of accident rates developed using data from one area might not be appropriate elsewhere, because of differences in reporting practices for non fatal accidents,
- some factors, that underlie relationships between safety and road design, change over time so that relationships developed at one time may no longer be representative in later years.

In order to get better insight into the safety effects of alternative road designs, the subjective safety experiment has been designed and conducted. In this experimental design another approach for safety measure was used. The subjective road safety assessed by the drivers reflects driver's subjectively perceived level of safety of the road situation.
The experiment has been primarily designed to test the effect of geometric road design elements and road environment on the subjective safety of rural road curves.

Accidents are more likely to occur on horizontal curves than on straight segments of roadway because of increased demands placed on the driver and the vehicle. Over 50 percent of the total number of accidents on rural two-lane roads involve single vehicle accidents on curves.

The safety effects of an individual curve is influenced not only by the curve's geometric characteristics, but also by other factors related to the road environment, driver's behavior and perception, and many other factors. The estimation of the combined effects on safety of roadview related factors was the main objective of this study. The experiment results provide more insight into the nature and extent of the risk produced by the road curve perceptible characteristics manipulated, which almost always occur in combinations.

Experimental design

A multi factorial experiment has been designed to test the effect of road curve characteristics, road environment and driver's experience on the subjective safety of rural two-lane roads.

Method

Forty licensed drivers of different driving experience were tested in laboratory conditions. Subjects were asked to give a rating of the presented road situation (the approaching zone of the curve and the curve itself of different geometric and environmental characteristics) that reflects the subjectively perceived level of safety.

The subjective rating scale was used as safety measure. An important assumption underlying the use of this measure is that subjects are able to verbalize the amount of perceived safety in an adequate way.

Ganton & Wilde (1971), performing an experiment in order to test the usefulness of a verbal rating scale of estimated danger assumed, that drivers are sufficiently aware of the change of estimated danger to be able to report it verbally. Wilde (1982) concluded that subjects are able, when asked, to express their perceived level of risk. Moran (1983) investigated the relationship between objective safety and subjective perceived safety. As a measure of objective safety the numbers of accidents per 10^6 vehicle/km travelled was evaluated for each road section. Subjective safety was evaluated by asking the subjects to estimate the amount of perceived safety in the tested situation. It was found that the objective accident risk correlated positively with subjective risk rating per unit distance. Grant (1985) stated that verbal rating measure constitute a cognitive representation of the concept of perceived safety.
Rating scale

Different rating scales with respect to the number of scale points and the definition of scale values were used by different experimenters: Ganton & Wilde (1971), Browning et al. (1977), Moran (1983), Grant & Wilde (1985), Huddart (1978), Zakowska (1989).

Taking together the psychometric advantages and psychological disadvantages of many scale points, a rating scale of 7 scale points was selected as the most appropriate in this experiment.

A second property of rating scales concerns the distinction between graphic and numerical scales. For several reasons, the graphic scale is preferable to the use of numbers without the graphic scale (Nunnally, 1978). With the graphic scale employed in this experiment (Fig. 1) the subject has to mark the appropriate box, corresponding to the numerical scale that could be defined as follows:

1 - unacceptable risk perceived
2 - very much risk perceived
3 - much risk perceived
4 - intermediate risk perceived
5 - little risk perceived
6 - very little risk perceived
7 - no risk perceived

Here only extreme scale points are defined. The interpretation of the undefined scale points was left to the driver, assuming that the distance between the scale points had to be considered as equal.

Figure 1. Rating scale used in the experiment.

Stimulus material

Two-lane rural highways of the southern Poland were chosen as an experimental polygon. The approaching zones to the selected horizontal curves (ab. 300 meters long straight segments before curve) together with the curves were filmed on video, as moving perspective road view observed from driver's eye position. The perspective viewpoint was the front seat viewing point of a driver in a vehicle positioned in the right-hand lane, with 1.20 m eye height, as specified by the National Standards in Poland (the similar specifications to those recommended in RAAL and AASHTO). Vehicle speed was the same as the designed speed for each site.

To eliminate the influence of not manipulated external factors, all sites were filmed at summer driving conditions, good light and weather, and none or limited traffic on the road.
Curve geometric features (curve radius and deflection angle), character of road environment and curve direction were manipulated in the experiment. Ten levels of curve geometry (radii of 150m, 300m, 500m, and 700m crossed with angles of 9, 18, 36 and 72deg), 2 curve directions, 2 categories of road environment (opened and walled roads) and 2 levels of viewing distance to curve (6sec and 3sec drive to curve) produced 80 stimuli, that were presented in the preorganized order, in four sessions of 20 road views each.

Subjects
40 licensed drivers took part in this experiment. They were selected and tested in four groups of 10 drivers of different driving experience. The groups were classified as follows:
1 - experienced road designers and drivers (over 100,000 km driven, and at least 10 years experience in road designing)
2 - very experienced drivers = professional drivers (min. 300,000 km driven and min. 10 years of practice)
3 - experienced drivers (20,000-100,000 km driven, min. 5 years driving)
4 - unexperienced drivers (less than 10,000 km driven, max. 2 years of holding driving license)

Procedure
The group presentations were used in this experiment. Subjects were seated in laboratory in front of 28" color monitor screen, having a good view on the screen, and they were discouraged from communicating during the experiment. A pre-recording type of experimental instructions and the practice film were presented as a training at the start of the session. Than the sequences of 20 film-clips were presented, with 30sec of blank film between each clip, when subjects made their assessments on the response booklet provided beforehand. The whole experiment consisted of 16 sessions, each of about 45 minutes long.

Results
Safety estimates were scored (from 1-for very unsafe, to 7-for very safe), recorded and analyzed using analysis of variance and the omega-squared statistics. The latter measure allows to estimate the strength of statistical relationship in terms of the percentage of variance accounted for by a particular manipulation (Hays, 1984). Statistical effect can be graded in terms of importance on the basis of the omega-square value (here, the value is shown in percentage of an explained variance). Using this approach, the stronger effects can be selected for more detailed attention.

In these studies, only significant effects explaining more than 0.5 percent of the variance were considered. All significant effects and interactions are enlisted in the figure 2.
Figure 2. ANOVA summary table of significant effects

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>MS</th>
<th>F-ratio</th>
<th>Explained variance%</th>
<th>F prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>geometry</td>
<td>1.1885E+4</td>
<td>1.1885E+3</td>
<td>1.149E+3</td>
<td>22.50</td>
<td>.0000</td>
</tr>
<tr>
<td>geom. &amp; dir. &amp; envir.</td>
<td>4.094E+3</td>
<td>4.904E+2</td>
<td>4.572E+2</td>
<td>4.80</td>
<td>.0000</td>
</tr>
<tr>
<td>geom. &amp; direction</td>
<td>4.084E+3</td>
<td>4.084E+2</td>
<td>3.472E+2</td>
<td>4.77</td>
<td>.0000</td>
</tr>
<tr>
<td>envir. &amp; geom.</td>
<td>2.814E+3</td>
<td>2.814E+2</td>
<td>2.494E+2</td>
<td>3.25</td>
<td>.0000</td>
</tr>
<tr>
<td>distance &amp; geom.</td>
<td>9.954E+2</td>
<td>9.954E+1</td>
<td>7.424E+1</td>
<td>1.04</td>
<td>.0000</td>
</tr>
<tr>
<td>geom. &amp; dir. &amp; dist.</td>
<td>6.765E+2</td>
<td>6.765E+1</td>
<td>6.004E+1</td>
<td>.68</td>
<td>.0002</td>
</tr>
<tr>
<td>geom. &amp; envir. &amp; dist.</td>
<td>6.167E+2</td>
<td>6.167E+1</td>
<td>5.444E+1</td>
<td>.61</td>
<td>.0006</td>
</tr>
<tr>
<td>geom. &amp; experience</td>
<td>9.943E+2</td>
<td>2.983E+1</td>
<td>2.362E+1</td>
<td>.62</td>
<td>.0233</td>
</tr>
<tr>
<td>geom. &amp; exper. &amp; envir.</td>
<td>7.628E+2</td>
<td>2.543E+1</td>
<td>2.252E+1</td>
<td>.51</td>
<td>.0447</td>
</tr>
<tr>
<td>envir. &amp; direction</td>
<td>4.609E+2</td>
<td>4.609E+2</td>
<td>1.952E+2</td>
<td>.53</td>
<td>.0230</td>
</tr>
</tbody>
</table>

Applying this criterion, the only main effect of curve geometry, and 9 interactions need to be examined. Curve geometry was the only significant main effect (22.50% explained variance, p<.0001). Also the highest range interactions included manipulations of curve geometry. Additional studies have then been performed to analyze the effect of curve geometry more detailed. This involved manipulation of curve radius alone, with the constant level of angle, and curve angle manipulation when the radius level is not changed.

Figure 3. The effect of curve direction and the character of road environment on subjective safety of curves.
Among other interactions, very interesting was an interaction of curve direction and the character of road environment (fig. 3). Subjects found open curves as more safe than walled ones, where the inner edge of curve is not visible. This distinction was stronger for right-hand than for left-hand curves, regardless the variable curve geometry.

Curve geometry manipulations
When manipulating curve deflection angle for small curve's radii (150 m) angle was the only significant source of subjective safety variation (17% explained variance, p<.0001). An interesting interaction of curve angle and driver's experience was also significant (for open curves: 5.7% expl. var., p<.001, and for walled curves: 2.1% expl. var., p<.05). Curve angle occurred to be an important factor deciding of the level of subjectively perceived risk of small radii curves. This effect is strongly influenced by the character of environment, as well as by the curve direction (fig. 4).

Figure 4. The effect of curve angle, curve direction and curve environment on subjective safety of small radii curves.

Figure 5. The effect of curve angle and the character of curve environment on subjective safety of 300 m radii curves.

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Angle was also significant for 300 m radii curves (40% expl. var., p<.0001). This effect is again stronger for open curve environment (fig.5). Surprisingly, no driver's experience effect on safety assessments was found here.

Also significant was angle for 500 m radii curves (16% expl. var., p<.001), and interaction of angle and driver's experience (6% expl. var. p<.005), as the only significant interaction for this radius level curves. An interesting effect of experience of drivers (fig.6) suggests, that with the growing experience, drivers are less sensitive to curve angle changes with respect to safety perception.

![Graph showing the effect of driving experience and curve angle on subjective safety of 500 m radii curves.](image)

Figure 6. The effect of driving experience and curve angle on subjective safety of 500 m radii curves.

Manipulation of curve radius for all tested levels of deflection angle revealed the importance of composed effects of four factors on safety perception. As the highest rank interactions may be regarded as the most important in this study, four interactions should be mentioned:
- radius & direction & environment & distance (3% expl. var., p<.0001),
- radius & environment & direction (2.8% expl. var., p<.0001),
- environment & direction (3% expl. var., p<.0005),
- radius & direction (7% expl. var., p<.0001).

Two main effects were also significant:
- radius (13.5% expl. var., p<.0001), and
- environment (2.8% expl. var., p<.0001).

Surprisingly strong effect of curve environment on safety assessment, regardless the level of curve radius, may suggest, that visual curve environment is an important factor in subjectively perceived safety of curves. This effect is illustrated in fig.7. It should be noticed, however, that curve geometry is an important factor, well discriminated by drivers, as presented in fig.8. Also radius affected the subjective safety strong enough, not to be neglected if compared with the angle effect.
Conclusions

This experiment has shown that drivers are able, based on motion road views, to discriminate different levels of perceived safety of curves. The results revealed the complexity of the effects on safety of rural curves. A general conclusion of this experiment is that road environment constitutes an important factor of curve safety estimation.
The main effect concerning curve angle and radius effect on subjective safety supports the findings from previous studies performed in driving simulator (Tenkink & Horst, 1991).

The advantage of the method used in this experiment (employing filmed road views) in relation to driving simulator is, that it allows to study the effect of real world driving environment on safety in more complex way. Difficulties in selecting and controlling the stimuli set, however, may result sometimes in lowering the accuracy of results.

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HUMAN FACTOR
TECHNOLOGICAL SUPPORT FOR DECISION MAKING IN A SAFETY CRITICAL ENVIRONMENT

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Abstract

In this paper, we explore the characteristics of a safety critical domain, that of Air Traffic Control, and discuss the possible impact of new technology on safety levels. Based on insights derived from ethnographic methods, we argue it is through the organisation of working practices as a teamwork activity, rather than through any technological fail-safe, that safety in the airways is currently maintained. An emphasis on the social organisation of work raises issues concerning the impact of technology and safety which hitherto have not been fully examined. In safety-critical domains, we suggest, the transformation of work under the auspices of new technologies may have negative consequences for safety at least in the period of transition. Careful management of technological change may well prove to be necessary if such problems are to be avoided. In particular, technological solutions to problems in working will need both to ‘resonate with existing practices’ and support more radical transformations in the future. The findings we present are the result of ongoing collaboration between computer scientists and sociologists. We discuss a user interface prototype generator which allows the construction of a variety of ‘views’ of ATC ‘objects’, and thus both supports current practices and allows transformations ‘down the line’ as new technologies and procedures become incorporated.

The characteristics of Air Traffic Control as a safety critical domain

It is common knowledge that travel by air is one of the safest transportation methods available to the voyager. When accidents occur, as of course they do in even the safest of systems, those attributable to Air Traffic Control (ATC) constitute only a small fraction of the total. Nevertheless, there is general agreement that the system is, as it were, under some ‘strain’ as a result of the vastly increased levels of traffic in the airways during the

1 Safety is of course a function of several factors, only one of which is ATC. The most important, and successful, innovations, have been ‘on board’ systems such as Inertial Guidance Systems; Ground Proximity Warning Devices; and more recently Collision Avoidance Systems such as TCAS, which has undergone lengthy trialling in the USA. Global Positioning Satellite navigation seems another near future development.
course of the last ten years or so. The situation is caused broadly by two countervailing demands. On the one hand there is the demand for the needs of both airlines and passengers to be met through a cost effective and time-efficient system for getting aircraft to their destinations by the cheapest and quickest routes where possible. At the same time, there is the overarching requirement that overall safety levels be maintained and where possible enhanced.

One does not have to be a domain expert to recognise that there is a sense in which these two demands are contradictory. In consequence, the late 1980s saw the introduction of Flow Control for the first time on a regular basis in British airways, whereby systematic limits were placed on the number of aircraft allowed on certain routes at periods of intense activity, in order to cope with traffic flow safely. (The period between 1971 and 1989 saw the number of commercial flights into and out of British airports more than double, and the number of passengers effectively treble (C.A.A., 1990)). The cost, exacerbated by the lack of a single European standard for Flow Control arrangements, was a rapid deterioration in the number of aircraft arriving at their destinations on time.

Flow Control in that context can be regarded as a necessary evil. Certainly, most controllers in the UK see it as an inefficient and cumbersome way of regulating the flow of traffic. In short, it may be argued that traffic flow at the next ‘peak’ - sometime after the current recession - will be considerably in excess of that reached in the late 1980s, and that the current system will prove unable to cope with that increase. It is hardly surprising, therefore, that a great deal of research effort has gone into the provision of technical support for Air Traffic Controllers (ATCOs) which would enable levels of both safety and expedition to be maintained whilst dealing with higher levels of traffic flow.

At the same time, the putting in place of new technologies to provide the necessary support has not been a resounding success. The British experience has been that various new facilities, most notably that of ‘RD3’, have been underused, sometimes ignored entirely, sometimes met with unremitting hostility, and when successfully incorporated, only so after lengthy transitional periods (see Hughes et al., 1988; Harper et al., 1991). ATC in the UK currently remains a surprisingly ‘low tech’ endeavour where paper continues to have a high profile in the work routines of practitioners. The available evidence seems to suggest the presumption that technology by itself can provide solutions to the problem of safe transportation at higher capacity levels is unwarranted. In turn, if new systems are to be designed which serve the broad purposes outlined above, they will need to be attentive to issues that arise from the character of work in a safety critical domain such as ATC. Broadly, these issues include:

- Safety critical systems often require highly skilled operatives to work together in complex ways. The nature of the ‘skills’ that operatives in such domains deploy, however, while potentially crucial for the maintenance of safety, is often both subtle and elusive and may not be adequately captured by notions such as distributed cognition. Concepts such as cooperation and coordination which have evolved from the interdisciplinary field of Computer Supported Cooperative Working (CSCW) give an alternative ‘broad brush’ characterisation of what we would argue are inherently ‘social’ features of work (Hughes et al., 1991), and furnish us with the opportunity for a fine detail rendering of how those concepts are manifested in the social
organisation of work through the use of ethnography. Such approaches provide us both with a detailed understanding of current work practices and potentially with a vehicle for identifying their relationship with technological innovation.

There is a growing awareness that the specification of such relationships is a vital issue in the design of new systems for complex organisations (see for example Grudin, 1988) but at the same time that it is not one that is easily formalised. It is, we argue, through this understanding of the ‘texture’ of work that a picture may begin to emerge of what relevant technology might be and how it might become successfully incorporated.

- Safety critical systems often have a form such that they cannot be easily shut down for any extended period, if at all. There is a general awareness that this means development must be incremental in nature, but this has not for the most part been accompanied by analysis of the relevance of formal training for, and more importantly informal ‘gearing into’ or familiarisation with, new systems. Little attention, for instance, has been paid at all to the time scale over which new systems may become incorporated, and their personnel, rostering, and management consequences. The processes by which new technologies become trusted and familiar are not merely a function of those technologies, but of several relevant organisational matters as well. It would follow that the problem of delineating the pathways to successful incorporation may be more tractable if we can understand how trust and familiarity are embedded in use.

The purpose of this paper, then, is to examine how new technologies in the domain of ATC may be developed which will prove relevant to the dual requirements of safety and expedition through an understanding of the work as it is currently constituted, and to suggest design features which will render incorporation less problematic.

Controlling work, the ‘trustability’ of paper and the culture of support

The focus of our studies, encompassing two lengthy periods of ethnography at the London Air Traffic Control Centre (LATCC), was on controlling activity as teamwork in a ‘working division of labour’ (Anderson et al., 1989). In this respect it was at the outset a specifically sociological study, which contrasted with the cognitive psychological and task analytic perspectives that had previously been brought to the domain.

There is a considerable literature from these latter perspectives which focuses on areas of interest such as stress (see for example Hancock and Warm, 1989); mental modelling (see for example Rasmussen, 1986; Mogford 1991); and error generation (Reason, 1987; Stager and Hameluck, 1988) and in many instances argues the case for their relevance to issues of automation (see Wise, Hopkin and Smith, 1991, for an overview). It is somewhat surprising, therefore, to find almost no mention of cooperation and coordination as features of the relevant and skilful work of ATCOs. Our contention is that

2The combined total time spent at LATCC was not far short of a year, although the length of, and time in between, each period of observation varied so that we could see ATCOs at work in a variety of conditions.
this constitutes a significant omission, for if these, in addition to those more individualistic skills identified in the above literature, are important to safe working then their attenuation by allocation of these functions to technological components may prove deleterious to safety. Our analysis focuses on two aspects of the social organisation of work which we believe have consequences for automation and safety. Firstly, we show how it is in and through the collective attention to paper based information that errors are handled, and safe working in general is manifested ‘on the suite’, and secondly how in and through active coordination, the culture of support that acts as a guarantor of ‘inter suite’ attentiveness is maintained.

Before this, however, a brief description of ATC work is necessary. ATC work takes place around the locus of the ‘suite’. The suite is a physical manifestation of the sectorisation of controlled airspace, in that the radar controllers on the suite are responsible for one sector each. In addition there is a Chief Sector Controller (‘chief’) with responsibility for strategic planning, and at least one Sector Assistant (‘wing’) responsible for allocating paper flight progress strips (see later) to their ‘correct’ positions. The sectors themselves can be conceived of as ‘blocks of sky’ with defined horizontal and vertical dimensions. Aircraft fly from one ‘reporting point’ to another using Inertial Guidance systems along routes which traverse those sectors.

For the individual radar controller, the primary responsibility is the safe expedition of traffic within their sector, and the coordination of that traffic in and out of the sector as aircraft are ‘passed’. The controller’s problem, as it were, is a scheduling one. He or she in receiving a steady stream of traffic into the sector must organise and make orderly the flow of that traffic so as to avoid mishap, and with due recognition of the need for flights to be expedited as effectively as possible. Available to the controller are both a set of rules governing procedure as laid down by the Manuals of Air Traffic Services, and a number of information sources. The latter can be described as taking three forms. Information is available directly from the radar screens and the printed paper strips, and indirectly and more intermittently from other operatives, including those ‘on the suite’ by word of mouth, those on other suites through, most frequently, the telephone, and from pilots via the R/T.

Both the radar and the paper strips present information from database processing applications - Radar Data Processing (RDP) and Flight Data Processing (FDP). The radar picture, though processed, provides a ‘real time’ representation of the relative positions of aircraft. Each aircraft appears as a ‘blip’ with a data block containing the Callsign of the aircraft and its height. It is important to realise that necessary though this data is, it is by no means sufficient to the task of controlling. It depicts only the ‘current state of play’. Of more importance is information about route, destination, estimated arrival times, requested heights, aircraft profile, and so on, all of which is found on the printed paper strips. These strips are produced from original Flight Plans submitted by the airlines and each presents information regarding one specific aircraft. They are updated manually either as aircraft

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3 There would in normal conditions be two radar controllers on any one suite, each responsible for one sector. There can, however, be as few as one, or as many as four, depending on conditions. Sectors can be ‘bandboxed’ i.e. joined together, at quiet times, or ‘split’ when there are heavy traffic loads.

4 ‘Reporting points’ are normally radar beacons of one kind or another.
pass over reporting points or as new information is input at the suite. They are thus, and unlike radar data, not 'real time' information displays.

Nevertheless, the strips are a vital resource for controlling work. In use, the printed data is quickly overlaid with a considerable amount of written information of considerable variety, including changes in flight levels, in route, in estimated times, etc. as instructions are given or as new information becomes known. One discovers also that not only are strips written on, but that anyone can write on them. They serve to provide the controller and his/her colleagues with a history of events, a record of intentions, and act as a resource for deciding 'what must be done next'. As each instruction to an aircraft is given, the controller records the change in pen on the strip. When coordination is effected, again the fact is recorded. New information about changes in estimated times can be appended by any member of the team. In addition, anything can be written on a strip. While standard formats exist for much standard information such as flight levels, it is normal to see a variety of signs, squiggles, written comments, and so forth, all of which are attention getting devices for the controlling team. In short, the strips are robust, flexible, and publicly available 'at a glance' to all members of the suite.

From knowledge of the manuals and the database alone, ATC appears to be a tightly circumscribed and highly rule governed system. Observation of the routines of controlling work in contrast enables one to see that in reality there is considerable flexibility in individual practice, and a highly informal 'working division of labour', where 'things to do' are allocated among the personnel on the suite according to principles that are determined from 'work in hand' rather than formal procedure. In other words, neither the procedural rules nor the database fully circumscribe the working practices of ATCOs and their colleagues.

Moreover, it quickly becomes apparent when one focuses specifically on database information that there is no inherent technological fail-safe whereby the available information can be guaranteed accurate. Rather, variations on this quote from one controller are commonly heard: "If you assume the information you're getting is wrong more times than its right, you'll be right more times than you're wrong." Thus, and for instance, radar faults can produce intermittent errors which must both be recognised for what they are and dealt with. Perhaps more importantly, (and it is surprising to discover that the typical controller regards the strip information as more indispensable than the radar display), the paper strips which are the locus of so much controlling work often either contain incorrect information or fail to arrive at 'timely' moments.

In both instances the information is not in itself reliably trustworthy. Trustability, we find, is arrived at through the medium of the interpretative work done by cooperating personnel on and across the suites. It is not uncommon even in the case of what appears to be the most routine of the activities such as those performed by assistants - involving the tearing off of the strips from the printer, placing them in holders, and transferring them to the bays in front of the controller - to discover that an initial check that the information on the relevant strip 'makes sense' in terms of route structure, times, etc. results in the discovery of error. It is through the constant checking of data by all members of the team, by the various means used to 'draw attention to' significant changes, and above all by constant mutual
The importance of mutual attentiveness is equally evident in the work of coordination. The need for the active coordination of aircraft across sector boundaries is without question a time consuming activity and has led to considerable attention being paid to the possibility of reducing it. At the same time, it is a somewhat puzzling feature of coordination that it does not appear to reduce in direct proportion to declining levels of traffic. We believe that this can be explained through attention to the social aspects of coordinating work. Whereas task orientation to coordination might lead one to presume that it is in the interests of everyone that such communications are kept to the necessary minimum, a sociological orientation suggests that rather more than task completion is in fact at stake when coordination work is done. Our observations suggest that background conversation during coordination work, including apology for inelegant work, explanation of decisions, and justification of solutions serves the important function of maintaining attentiveness to other people’s problems. All in all, it is a constituent feature of the passing of information by coordination that it is done actively. Attention to that information is therefore guaranteed in and through that activity. In passing, it should be noted that similar conversations saturate controlling culture, and are to be found in data which encompasses not only work activity but also coffee breaks, talk around the suite, late night ‘war stories’, and so on. All of these things feed into the culture of support in important ways.

Perhaps most significantly, this is manifested in the ways in which mistakes are dealt with. In any system, error is to a degree inevitable, although as Stager and Hameluck (1988) point out, such errors may be categorisable in a variety of ways. In any event, for the controller working within such a culture, the issue is not one of error generation but of error handling. Controllers recognise that mistakes are made, and indeed view them as part of the ‘routine troubles’ of work. The culture of support manifested in coordination work and so on can be recognised as a means of minimising the consequentiality of error in that oversights, incorrect level allocations, etc. are routinely detected and pointed out by people who are not necessarily responsible for the section of sky in which they take place.

Designing relevant technologies

As we have stated above, the current system is under strain. There is a prima facie case for technological support for controlling work. At the same time we are confronted with a history of technological innovation in ATC which has been met with some hostility on the part of those operatives it is intended to support. Controllers’ arguments of course include concern about ‘deskilling’, conditions of work, and the possible reduction of staffing levels but, and to stress the point, it is regularly accompanied by a strong claim for safety and effectiveness predicated on the very teamwork we have described above. Their reservations about new technologies reflect their concern that such innovations should be

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5Not all aircraft have to be actively coordinated. Those passing sector boundaries ‘straight and level’ at agreed levels laid down in the manuals can be handed over ‘silently’.
relevant and geared to their practices as currently constituted and their view that all too often it has historically not been.\textsuperscript{6}

Our research concern was to inform the design of a prototyping facility for an electronic version of the paper flight strip which would be relevant to controlling work (Bentley \textit{et al.}, 1992a, 1992b). There can be no doubt that an electronic version would furnish a number of useful functionalities, including a more effective conflict alert facility\textsuperscript{7}, closer links between RDP and FDP and thus between the radar and the strips, and a reduction in the number of strips which require displaying. Additionally, it can be argued that it would open up the possibility of semi-automated coordination procedures (see Shapiro \textit{et al.}, 1991 for a fuller account). At the same time, it is clear to us that a direct equivalence between paper representation and representation ‘under glass’ cannot be presumed.

Current screen technology is such that without careful consideration of the issue of teamwork there is a serious risk of attenuating the public availability of information. To return to a point made earlier, technological innovation should not occur in isolation from working practices. There is no particular reason to presume that electronic display will eradicate information error, and thus there is a strong case for arguing that such a facility must allow for the mutual attentiveness and ‘checking’ we have described, possibly by re-distributing work among ‘tactical’ and ‘strategic’ controllers. Regardless, important decisions will have to be made concerning the number of screens available and the way in which data is to be shared between them. Equally, the fact that automated coordination is technically feasible should not obscure the fact that reducing coordination may have the unintended effect of reducing other cooperative activity. One negative consequence of automatic coordination might well be the automatic promulgation of error. Certainly, if it were the case that information that has hitherto been written on paper and passed by word of mouth is instead input directly to the database and automatically distributed, there is a real danger that errors might be transmitted \textit{and acted upon} before they are recognised as such.

We are therefore conservative in our view of what degree of automation of coordination should take place in the near future. The prototyping facility we are in the process of designing is intended to support modest and incremental changes to the user interface by allowing representations ‘under glass’ which will be familiar to the controller who is used to paper versions, and will retain as far as is practicable the publicly available nature of paper. At the same time the prototype provides a means for more radical experimentation with display and coordination possibilities so as to meet the challenges of the future.

\textsuperscript{6}It is by no means the case that controllers are hostile, or even indifferent to, all technological support. The conflict alert facility is an example of a facility that has become trustably incorporated, despite the fact that in its current form it throws up large numbers of spurious confictions. In the words of one controller, “I don’t mind if its wrong 99 times out of a 100 ... though it can be a bit distracting ... as long as its right the one time ...”

\textsuperscript{7}Spurious confictions are a result, more often than not, of the fact that the RDP does not have access to controllers’ intentions, which are recorded only on the strip. Were that information to be recorded electronically, it would be immediately available to the database.


It may well be true that at some point in the future Global Positioning technology and Collision Avoidance Systems may provide pilots with information resources and decision support facilities as sophisticated as those in use by controllers today. At such a time, it is possible that the culture of support and mutual attentiveness may become less important as a validating mechanism for safety than it is today. Then, controlling work may indeed become more individualistic and nonetheless as safe as it is at the moment.

Conclusions

In summary, controlling work will change. It is our view, however, that the process of change cannot be safely managed by presuming a ‘jump’ to radically new technology and practices. Rather, it should be recognised that as these changes work through the system, a means must be found of ensuring that each innovation can be trustably incorporated into controlling work. In sum, it is in the careful management of that change that this is most likely to occur. Because current practices are the way in which safety levels are maintained, it is important that innovation does not radically intervene in those practices. At each stage, the opportunity for controllers to familiarise themselves with new facilities in and through the web of work should be available. It is our view that in safety critical systems this is as important as formal training schedules, because it is in making such systems trustable that they are made to work. It is unlikely that this will be done if the means by which this trust is managed is attenuated by those very technologies.

References


KEEPING THE PILOT IN THE LOOP

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Abstract

All too often in the media, human error on the part of the pilot and other crew members is headlined as the primary cause of air accidents. Fokker Aircraft believes this emphasis to be incorrect and that it results in an inappropriate reaction by the public, politicians and the aerospace industry.

The first change that has to be made is in what is meant by 'human error'. The term needs to be re-defined to embrace all human involvement in flight. It should cover any design and manufacturing errors, training and airline operational errors, air traffic control errors, and finally aircrew errors.

A review of all aircraft incidents and accidents over the past ten years would almost certainly show that the investigators all too often concluded that the cause originated with 'crew error'. What in effect they were saying was that they did not know why the crew took the wrong action - or no action - but in the event they, the investigators, feel secure in describing it as crew error.

Since investigations typically conclude with this type of finding, in many cases no further action is taken to determine the real cause. Unfortunately such a situation results in no insight being gained into possible design errors or other mistakes. Undoubtedly flight safety would greatly benefit if such investigations were taken further.

To give some idea of the sort of errors that get made during design, the following are three examples of incidents which occurred on Fokker Aircraft. They demonstrate how the real source or cause of incidents can often get overlooked.

The first example concerns the engine and gearbox low oil pressure warning lights on the F27. The engineer who originally designed the instrument layout appears to have thought that a single inscription on the panel plus two similar warning lights, was the best solution both technically and economically.

Banded Warning Lights

This resulted in a layout (Figure 1) in which both the left and right-hand (RH) oil low pressure warning lights were positioned under the left-hand (LH) engine's instrument group. Likewise, the LH and RH gearbox oil low pressure warning lights were located under the RH engine instrument group. The likely mistake that pilots will make with such a display is that if the RH engine oil low pressure warning light illuminates, the pilot may shut down the LH engine. For this reason the design was later modified to group the respective LH and RH warning lights with the appropriate engine instruments.
The second example concerns the provision of a high turbine gas temperature (TGT) warning on the F28. This alerts the crew during taxing when engine TGT exceeds a predetermined limit. The design engineers decided that the normal reaction to such an alert would be to retard the throttles. As this was seen as the same reaction as to a Vmo/Mmo (Vmo = maximum permitted operating speed - Mmo = maximum permitted operating Mach number) overspeed warning in flight, use could be made of the same warning horn.

In reality, however, crew reaction to a Vmo/Mmo overspeed warning is somewhat different. The overspeed almost always occurs during descent when the throttles are already in the idle position and the pilot normally uses the speedbrakes to decelerate the aircraft. Hence, confusing by pilots concerning a high TGT warning on the ground (i.e. by the Vmo/Mmo overspeed warning horn), is only human. In the particular instance being cited, the pilots did not take corrective action.

In the third example, in which a non-fatal accident occurred, the official investigation stated that pilot error was the cause. But who can say with certainty that it was pilot error, or should not equally or alternatively have been attributed to design error? The accident took place during landing when an F27 alighted with all gear up. The landing gear handle was in the 'up' position and the 'landing-gear-not down' warning horn had been silenced. The design requirements for landing gear position indication and warning are defined in Federal Aviation Regulation (FAR) No. 25.729 (e). This states that "Land planes must have an aural warning device that will function continuously when one or more throttles are closed, if the landing gear is not fully extended and locked."

In many aircraft this requirements has led to the installation of a muting button to cancel the 'landing-gear-not down' warning horn. Without this, every time the pilots retard the throttles - even at the top of the descent - the warning horn will come on. Not unnaturally pilots acquire the in-flight habit of depressing the landing gear silencing button simultaneously with closing the throttles. From a human factors' point of view, the accident scenario was obvious: the pilot pushed the button coincidentally with retarding the throttles for landing.

Experience applied to Fokker 50 and 100

The experience gained from this incident was applied to the design of the 'landing-gear-not-down' warning system on the Fokker 50 and Fokker 100. On both aircraft the gear warning can be sounded only at heights below 1,000 ft. The design also ensures that after the warning has been given and the crew has taken the correct action (i.e. selected landing gear handle down), the aural and visual 'attention-getters' are cancelled for the period the time that the gear status is indicated by an annunciation. Initially, neither the design to obviate nuisance 'landing-gear-not-down' warnings not the cancellation of the 'attention-getters' was approved. This was because they did not comply with the letter of the FAR 25 requirement. For both aircraft programs, this resulted in a certification issue. However, by incorporating suitable modifications, Fokker was able to demonstrate that its aircraft still meet the relevant safety requirements.
Human Factors Design Aspect

During the design phase of the Fokker 50 and the Fokker 100, it was recognized by Fokker that 'human factor' aspects of aircraft operation and safety should be considered from the outset.

At the start of both programs, an operational analysis was made of a number of Fokker and other manufacturers' aircraft types. This analysis (Figure 2) provided the basis for all subsequent decisions and definitions concerning the operational requirements. And the requirements in turn provided the basis for defining the functions that has to be performed. After allocation of the functions, the detailed design of control, display and alerting systems was performed. This was not an attempt to re-invent the wheel. It was done to provide and engineering data base and to establish a consistent set of ground rules to be applied and adhered to during design of the flight deck systems.

One of the main rules adopted for both Fokker programs was the requirement to create 'situational awareness'. Before it became a marketing slogan, 'Keep the pilot in the loop' was an important design dictate for the Fokker 50 and Fokker 100 flight deck design teams.

The following examples provide an indication of how a better human factors' design has been implemented on the Fokker 100. First, with TCAS II traffic alert and collision avoidance system becoming mandatory this year, the retrofit application of this equipment initially focused attention on the vertical speed indicator (VSI). However, this represented a solution compatible with existing engineering constraints rather than a realistic attempt to optimize the human factor aspects. Nor was such a solution applicable to aircraft with an electronic flight instruments system (EFIS). For these aircraft a Resolution Advisory display allowed for optimization from a human factors' point of view. In the basic 'T' layout of the primary flight display, the primary flight parameters are embodied in a way which focuses attention on aircraft attitude. This enabled the design of a TCAS pitch cue instead of a VSI cue to be proposed and implemented. The resulting system was then evaluated on a full-flight simulator.

Monitoring Primary Flight Parameters

A very positive performance improvement was shown by this evaluation. Pilots favoured the display because it meant they monitored the primary flight parameters instead of secondary displays. Altitude awareness was another item which required particular attention. Fokker was one of the first manufacturers to introduce altitude and vertical speed indication on the primary flight display. This was aimed at providing an improvement over the conventional 'T' configuration of instrumentation (Figure 3). Compared with this, altitude awareness, scan distances and dwell times were all considerably improved upon (Figure 4). Even so, the perfect design where the pilot has a simple cue which provides him with 100% altitude awareness (in addition to reference altitude, altitude rate and height above ground), has yet to be achieved.
System Status Awareness

Automation in the Fokker 100 was carefully reviewed and was not introduced simply for its own sake. The main aims were to improve safety and assist the pilot. An example of how safety has been improved is the flight envelope protection in the autoflight system. This was designed to safeguard against low and high speed exceedances.

Pilot assistance is exemplified by the system status awareness given by the combined flight warning computer (FWC) and the multi-function display system (MFDS). These assist the pilot in monitoring engine parameters and system status. Where automatic failure recovery is required, the system keeps the pilot 'in the loop' by informing him of any failure and indicating the corrective procedure - although the system will already have automatically actioned the solution. The system ways require the flight crew to acknowledge all automated actions. After the action the system status is explicitly signalled to the pilot.

System Operations

For example, with a generator failure the system operation and failure handling of a conventional system and the improved system, may be compared as follows:

Conventional system operation:
- generator 1 fails
- automatic bus switching couples AC bus 1 to AC bus 2
- pilot performs emergency procedure
- generator 1 switches to OFF/RESET
- generator 2 'Inoperative' light still illuminated.

This required the pilot to:
1. notice and recognize the amber lamp on the overhead panel
2. obtain the procedure from the operating manual
3. see that the generator switch is OFF
4. assume that the forgoing action was successful
5. determine what the status is from the operating manual

Improved system operation:
- generator 1 fails
- automatic bus switching couples AC bus 1 to AC bus 2
- level 2 is alert indicated
- generator 1 'Fail' message signalled
- generator 1 'Fault' light illuminates
- corrective procedure shown on MFDS
- generator 1 switch 'OFF'
- aircraft status shown on MFDS

As a result the pilots are:
1. alerted there is a failure
2. automatically provided with a display of the procedure
3. given a clear annunciation that the switch is 'OFF'
4. provided with an action feedback
5. provided with a display of status
Difficulties be introduced however, where there is too strict an adherence to design objectives or rules. Conflict for example can be experienced between the 'quiet and dark cockpit' philosophy and 'keeping the pilot in the loop'.

When there is no problem, the first of these seeks to keep everything in the cockpit dark and quiet. It has happened that mistakes have been made in applying this rule. To avoid this, the philosophy is now being modified in favour of the 'pilot-in-the-loop' requirement.

One example of this is the 'take-off configuration test enabling the pilot to confirm that the aircraft is correctly configured for take-off. Initially the system was designed so that when the aircraft was in take-off configuration and the pilot pushed the 'take-off configuration' button, no alert was given if the aircraft was in fact correctly configured. The pilot was not in the loop however and did not know for sure that the test had actually been performed. For this reason, the system has now been changed to provide a feedback which positively informs the pilot that the take-off configuration is correct.

The Future

The application of new systems to the flight deck are increasingly and dramatically affecting its operational environment. One consequence of this is that the flight deck designer's biggest challenge has yet to come.

Recently-introduced systems such as windshear and TCAS have been incorporated as discrete systems, but with future changes and additions this may not be so straightforward. Data link systems with integrated air traffic control and artificial intelligence-based systems (i.e. pilot associate systems) will require a man/machine interface (Figure 5) far in advance of what is available today.

But whatever the level of complexity of future systems, it must be recognized that everyone in the aerospace community plays a contributory role in 'crew error' incidents. Although we may not present during crew actions, it remains our duty at the system concept and development stage to strive to understand and anticipate their actions and reactions. Above all we must: "KEEP THE PILOT IN THE LOOP."
THE BLACK BOX CALLED MARINER

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Abstract

This paper intends to focus the attention of researchers and rule-makers on the perception of the mariner of his task. It provides examples of automation and simulator research and training that highlight the need for a better understanding of for example the decision-making process and the evaluation of ship movements in the mind of the mariner. The paper pleas for research into this subject.

Introduction

An often heard statement in recent years is that human error causes 70-80% of all maritime accidents. In my opinion this statement is used too easily. If one includes improper design, design errors, construction imperfections, etc., the number of accidents caused by human error will be very close to 100%. Furthermore it is most likely that errors in design or construction, both on board of the ship or in harbour lay-out preceded a significant number of the human errors, that are related to mariners. However the statement has focused a great deal of attention on the seafarer's role on board of ships.

The measures taken to prevent or reduce the effect of human errors tend to be 'technical'. With the introduction of 'optimal' bridge designs many of the former tasks are automated, watch keeping alarms are introduced, standard procedures are drafted, etc. Little attention is paid to the seafarer himself. The use of task analyses when formulating measures is limited. If task analyses are carried out, most of the time the results are restricted to a summing up of the visible and most obvious part of tasks and the way they are carried out. In other words the analyses consider what goes in and what comes out of the mariner. What happens in between - inside the black box - is not included. Inevitably any resulting measures therefore lack detail. Quite often the people, that are subject to the measures, feel reluctant as the measures do not comply to the normal routine or to specific tasks. Following are a number of examples where knowledge of the perception of the mariner played or could have played an important role.

Bridge '90

The Dutch 'optimal' bridge design "Brug'90" was designed to reduce the number of human errors and to allow a smaller bridge team. The study among others incorporates the in my opinion best attempt so far to design an integrated navigation display. The manufacturers of ARPA-radars should take a close look at it. On the other hand the bridge has a push button telegraph
fitted, that allows 'dead slow', 'slow', 'half' and 'full' settings and fine adjustment of requested RPM's by a numerical input mode.

A more detailed task analysis would have shown that a push button telegraph does not fit the needs on board of modern vessels. More and more vessels have bow thrusters and sometimes high-efficiency rudders fitted to reduce the need for tugs. The manoeuvres with such vessels do not any longer allow the inevitable time-delay from orders to a mate and a helmsman: the captain manipulates the controls himself. For the same reason the telegraph on those vessels must allow immediate availability of finer adjustments than the traditional 'dead slow', 'slow', 'half' and 'full' settings. Although during sea-passages the numerical value of the RPM's is relevant when fine-tuning an economic speed, the numbers are irrelevant during harbour manoeuvring. The intermediate step of mentally translating the undefined need for 'a little bit more' engine power to a specific number of RPM's creates a useless and often unwanted delay and increase in work-load. It also does not make full use of the potential of the modern bridge-control, that allows immediate and continuous RPM control. Last but not least the push button telegraph lacks the immediate feedback through the sensory system of the hands that a lever can provide.

**Joystick control**

Another example can be found with the present generation of joystick controls. The joystick control was originally developed for dynamic positioning of offshore platforms and drilling vessels. These platforms and ships have a number of, e.g. six, so-called azimuth- propellers fitted and the task in question is to control the thrust and direction of these propellers to keep the vessel within one or two meters of a defined position in open sea. At one particular point the joystick control was introduced on board of ferries and later on also on board of cruise vessels. The idea was that bringing such ships alongside a jetty does not differ much from the dynamic positioning of a drilling vessel.

The front end of a joystick control consists of a rotatable lever for ordering the amount and direction of thrust, besides a direction control knob. With the more advanced models the direction control offers both a manual and an automatic direction control mode besides a knob to change the location of the - theoretical - rotation point from the centre to the bow or the stern. Balancing the output of the different manoeuvring means when no turning is required is automated by the joystick control for the situation where no external moments act on the ship. The supposedly advantage of the system is that the number of manoeuvring controls that the captain has to handle is reduced. On an average ferry these controls consist of two main engine telegraphs, two independent rudder tillers, one bow thruster lever and one stern thruster lever. Hence the reduction in controls seems significant.

Joystick controls may be a major improvement for bringing a ship alongside. However the ship must be reasonably aligned with its berth, when the change-over from manual to joystick control is made and only limited external moments should act on the ship. The disadvantages of joystick controls show up in those situations where a ship has to be moved through a restricted area at low speeds for a longer period of time, like in a very narrow channel with bends or a chain of harbour basins. During manoeuvring in confined areas the area of interest is usually not
the centre of the ship, but either the bow or the stern. For some reason, it is always one of the ship’s ends that is in trouble, i.e. too close to a pier or whatever solid object.

When the manoeuvre is done manually, the rudders with the telegraphs or on the other end the bow thrusters provide the opportunity to address such trouble in a very straightforward manner. One has the possibility, for example when the bow is in immediate trouble, to put the bow thrusters full away from whatever danger there is, and only next consider how to prevent any possible resulting trouble at the stern. With a joystick control one would have to consider whether a drift request or a rotation request and possible a change of the centre of rotation will put the bow thrusters to full and at the same time consider if the joystick control routine will not stop the stern thruster or put the rudders to another position. In other words with joystick controls the handling of the ship is no longer intuitive. Insufficient attention was paid in the design to the details of how manoeuvres are apprehended by mariners when it was decided to place the existing joystick controls on board of passenger ships. A future generation of joystick controls should take better account of the kind of manoeuvres that the vessels in question make and especially with the mariner who has to carry them out.

Cruise vessels

Sometimes however, progress demands to deviate from old habits. About four years ago I became involved by a simulator study regarding the passage of a narrow channel with a large cruise vessel. The vessel then had yet to be built and would be considerably larger than other vessels that passed through the particular channel. The question was whether the passage could be safely made with the designed vessel. The study started out as a normal simulator study. The results of the simulations however proved the passage with the existing design not sufficiently safe. One of the reasons for the lack of safety was quite easy to define: the customary speed in the channel and the channel characteristics resulted in excessive bank-suction at times. The other reason however was less well defined. Both the pilots and the captains that were familiar with the area indicated that the surroundings barely provided cues to judge the ship’s movements during the passage.

The possibilities to improve the position information appeared to be very limited. There were no suitable locations to locate additional buoys or beacons. It was therefore proposed to fit the vessel with high accuracy electronic positioning system, a two axis Doppler-log and a rate-of-turn indicator. The system should be capable of displaying the ship’s position and movement on a display that should also show a basic electronic chart. The solution to the bank-suction problem however was a technical one. To reduce the bank-suction it was recommended to lower the speed during the transit and to install stronger bow thrusters and high-efficiency rudders to compensate the greater wind-effect at the recommended speed.
Not unexpectedly it appeared to be necessary to develop a strategy to effectively use the new equipment. The recommendations were tested in a new simulator experiment and were found to be very effective from a technical point of view. However the recommendations itself created a new problem: the recommended strategy differed dramatically from what the masters and pilots of cruise vessels were used. For example one of the basic principles of the strategy, the use of the two main propellers’ moment, was exactly opposite to what the masters were used to. Clearly there was a need for training.

Several training sessions were conducted comprising different masters and pilots. The first training session appeared to be not only a training for the trainees, but also for the trainers. We had to define the strategy in an even greater detail than was already the case. For example even the rank and thereby frequency of monitoring the different sources of information, like electronic navigation system, outside view, doppler-log, etc. needed to be trained. During the training items like the previous experience of the trainees - to the detail of the controls on previous vessels - and like the influence of the attractiveness of a display on the frequency of monitoring, played a major role.

Judging from the operational success of the vessel - it is now in its third year of operation - we did a good job. An important factor may have been that we were invited to accompany every new master on his first trip on board of the vessel to facilitate the step from the simulator into reality. However to my opinion we could have done an even better job, or at least a more structured one if we would have had a better background regarding the perception of manoeuvres and information gathering by a master or pilot. The only tool we could avail of at the time, was a rather unstructured notion of the own perception during manoeuvring in reality.

**Push-tow barges**

A similar example is found in a recent study into the effects of bow rudders on the pathwidth of push-tow barges. On the Dutch part of the river Rhine push-tow units with 6 barges are only allowed above a certain water level, when the navigable fairway width is over a defined minimum. The admission policy is based on the so-called ‘fairway-strip’ theory, which is based on the path-width of standard types of inland barges. With this theory the sum of the path-widths of the vessels involved in a defined encounter have to fit within the available fairway width. Empty 6-barge push-tows have the largest path-width of all vessels that are allowed to navigate the Rhine and with lower water levels the defined standard encounter with a 6-barge push-tow involved does not fit within the available fairway width.
width. Naturally the operators of push-tow barges prefer to have the admission policy widened.

Following the ‘fairway-strip’ theory the admission policy can be widened if the path-width of empty 6-barge push-tows can be decreased. One possibility to do so is offered by a more active use of the bow rudders. This was studied by the Dutch department of public works by measurements on board of 6-barge push-tows travelling on the Rhine.

Furthermore a limited real-time simulator study was carried out. The conclusions of both studies were that a significant path-width reduction can be attained when a - from a hydro-dynamical point of view - optimal use of the bow rudders is made. However there appeared to be one problem: The skippers of the push-tows were very reluctant to co-operate both in reality and in the simulator. The reason for this reluctance is that when the bow rudders instead of the main rudders are used to sail through a bend, in the opinion of the skippers it looked as the push-tow would end up hitting the outer bend.

One should remember that the skippers in question are experienced push-tow skippers who have been navigating push-tow units between Germany and Rotterdam for years. While skippers of motor-barges may make the down-river voyage with a loaded vessel, these skippers always - in fact every other day - make this trip with empty barges that experience large drift-angles while sailing through the many bends of the Rhine. Reducing these drift angles creates an entirely unfamiliar situation, where the push-tow is steered in a different way, reacts in a different way and the position and movement information does not contain the normal clues.

It is likely that a systematic reduction of the path-width is not experienced as beneficial. Path-width is not a reference for push-tow skippers. Their problem is how to stay clear from the fairway limits and from other ships. In many cases during an encounter this will in effect mean that the path-width is reduced, but sometimes a collision avoidance manoeuvre will be made that effectively increases the path-width. The knowledge of how skippers or navigators evaluate the position - and the safety - of
their ship is limited. Very little is known of how exactly an encounter in confined and winding waters is evaluated. Which also makes it very difficult to judge what the effect will be on board of other ships. These skippers most probably also have an expectation of the behaviour of a push-tow and it is not unlikely that with the introduction of a different steering method of push-tows, the other ship will have difficulties with judging the safety of an encounter.

Not having knowledge of the internal processes in the mind of the skippers it is difficult how to make sure the bow rudders will be used systematically in real life. Enforcement is clearly difficult. The only possibility seems to be to define - by further research - a strategy for the use of bow and main rudders that reduces the path-width and at the same time reduces the work load of the skipper to make its use attractive. Such a strategy should hold in different situations including encounters. Additionally it will be necessary to train the present generation of push-tow skippers in a simulator how to use this strategy, while also the introduction in reality will have to be monitored closely to assist the skippers not to return to old habits conclusively after a tight situation is met. Finally it is not yet known whether it is needed and next how to introduce a different behaviour of empty push-tows to the large number of other ships on the Rhine.

Harbour design

That we know very little of the ship status gathering process in the navigator’s mind, is reflected in the design of many harbours. Nevertheless like every position fixing system the position fixing system that consists of the mariner’s eyes and mind has a specific accuracy that depends entirely on certain circumstances. - It is by the way better to speak of the ship status fixing, as judging the ship movements is most of the time even more important than the judgement of the present position. - Research has been carried out into the abilities of helmsmen to steer a ship in a leading line. The guidelines regarding the accuracy of leading lines nevertheless have little detail and even those guidelines are too often not followed. Almost 10 years ago I carried out a preliminary study into the behaviour of skippers and mariners. Even though these studies indicated the existence of specific methods to judge the ship status from outside cues, the main study, that should have investigated these methods systematically, was never carried out. Knowing these methods and the possible methods in the decision making of the navigator would allow to take them into account in harbour design. It would enable a systematic approach of providing cues to the mariner not only by buoys and beacons, but also in the lay-out of the basin.

A major problem with simulator research is how to do statistically sound statements on a too small number of simulations. For years the chance of grounding or hitting the shore was calculated using normal distributions. Using a normal distribution in channel design however assumes that it is possible to sail on the wrong side of the shore-line and it does not take into account that usually a captain or pilot will try to keep clear from the fairway limits. Knowledge of for example the decision-taking process and the methods and accuracy of the visual position fixing of navigators would enable to construct realistic statistical methods for analysing simulator runs. The PIANC guidelines for channel and harbour design - unintentionally - allow for among others the accuracy of the navigator’s ship status judgement. Taking into account the cost of the dredging that results from the size of the factors that are applied in these guidelines, investing in research in what is probably a major factor in the size of channels and harbour basins, would very likely pay itself back.
Conclusions and recommendations

Harbour and ship operators continuously seek to reduce building and maintenance costs of harbours respectively the operational costs of vessels. At the same time there is an on-going need to increase safety. It is my strong believe that with more knowledge and understanding of the perception of the man in the wheel-house both needs can be more effectively met. This knowledge would provide a more solid base to simulator research, training, bridge design, navigational aids, etc., etc.

I will conclude with a hearty plea for a joint effort to crack the skull of the mariner and see what goes on inside.
Abstract

Safety matters are boring, bothersome or just a cost factor. These are some of the arguments which prevent safety issues from being treated in the same way as, for example, transport logistics, i.e. rationally aiming at optimum results. National legal evolutions, resulting in distinct rules and regulations, are another handicap for a European approach to common marine safety standards. Political changes within the European Community offer a chance to create a marine safety system which complies with developments in shipping, operational practices, and requirements resulting from casualty investigations and statistics. The author is taking the opportunity of the Delft Congress on Safety of Transportation to propose the establishment of a European Marine Transport Safety Board under the umbrella of a European Transport Safety Board to mutually benefit from road, rail, air and sea transport knowledge.
Foreword

If the number of rules and regulations dealing with marine safety were an indicator for the level of safety obtained, there would be nothing to worry about. And since their number is still increasing, future prospects should be bright. Unfortunately that is not the case. But then how does one deal with the challenge of protecting human beings, the environment, company investments and marine economical interests such as fishing and tourist beaches if not by creating more and tougher rules?

We have got a unique chance. The abolition of the borders within the European Community by the end of this year requires common rules, regulations and procedures. Of course there is some danger that too many cooks will spoil the broth by everybody adding his preferred spice, i.e. rule, on top of what is already there. We might even need a small "revolt" by those subjected to existing regulations to enforce new and improved approaches for enhancements.

Marine Safety

"Safety matters are boring, bothersome or just a cost factor" is an often-heard opinion. So even if it is for their own sake it is difficult to convince people to perform safely or to pay for safety. Unsafe practices do not necessarily result in accidents. Thus it is not easy to prove benefits. The line of argument should therefore follow a more abstract approach by treating casualties as "undesired events" similar to, for example, technical disturbances of a production system. For this purpose a number of analytical methods are available which might convince people greater than just logical reasoning. It is probably because motivation to avoid technical defects is generally better than that to avoid injuries. There is nothing cynical about that: it is just because many people mentally suppress picturing possible events they are really afraid of, whereas improved safety requires a very conscious realization of what could happen.

Since the term "marine safety" is somewhat vague and might not always be used in exactly the same way, a definition is required. Within this paper, marine safety means "a condition which is obtained by applying all reasonable measures minimizing potential dangers to men, objects and environment caused by operating vessels".

Safety measures can comprise active measures such as

- technical measures and provisions when manufacturing or operating a system
- organizational measures within a working process
- behavioural measures to influence attitudes
or passive measures aimed at protection if threatening conditions cannot be avoided by active measures.

Often, risk is used to measure safety. Normally risk is determined by a figure resulting from multiplying average cost of casualty by probability of occurrence. Thus a real disaster which is unlikely to happen (but not impossible) might lead to a risk similar to that of a minor casualty with a high probability. Therefore it should be discussed whether the term accepted risk is appropriate for deciding what society might have to tolerate and what not. Assessment of potential danger describing the severity of a casualty elucidates much better what could happen.

**Rules and Regulations**

Most practitioners believe that rules and regulations are only made to prevent harm whereas lawyers require that rules and regulations follow clear and unambiguous principles for deciding after an incident who is to blame and, even more important within business life, which party is to be held liable for damage.

With regard to the preventive character of rules and regulations, the requirements are

- to reflect real situations
- to be easy to read and to interpret
- to be at hand when needed.

Within democratically organized societies, legal regulations take quite a long time from first recognizing that there is a need for change or amendment to finally coming into force. It must therefore be accepted that this process cannot keep pace with continuously accelerating technical changes. Technical rules which can be adapted faster to ongoing developments must fill that gap. This, however, is only possible to a very limited extent.

Agreed standards worked out by privately organized bodies cover a large area of details, but these too lag behind technical development.

The state of the art, describing in detail how a technical system should be constructed and how it should work and be operated, is not laid down comprehensively. Certainly there are professionals and scientific people with the potential of putting the jigsaw together which will finally present required knowledge and skills. However, it is not done on a regular basis. Manufacturers’ manuals, experts’ opinions, university papers and results from court cases where specialists were consulted must be collected, requiring a lot of effort.

Thus it must be accepted that rules and regulations can only provide the shell for safe systems and operation. Up-to-date knowledge and skills in great detail must be derived from other sources.
Within democratic societies, where the actions of politicians are strongly governed by the desire to become re-elected, creation of new rules and regulations provides a convenient way of demonstrating political efforts to the public. Especially after an accident, when the press calls for action to avoid similar casualties in the future, a working group is established immediately for development of new regulations to amend rather than to replace current ones. The result is obvious: the number of rules and regulations to be followed by continuously reduced crews, i.e. fewer and fewer people aboard, is much too large to be at hand within an operational environment which very seldom provides enough time to search through the books or ask other experts.

Current Developments in Sea Transport

Increases in individual transport, relatively low cargo transport costs and just-in-time concepts have caused a road traffic situation which in some regions is not far from collapse. At the same time, scientists are warning us that jet flights must be dramatically reduced because exhaust gas is destroying the earth's atmosphere. If that recommendation is followed, large numbers of passengers and tons of cargo will add to existing land transport. Now that the Eastern countries have been released from the Iron Curtain, their economic development, which is expected to happen soon (hopefully), will cause additional flows of cargo throughout Europe.

Sea transport capacity could probably be increased to allow for the shifting of passengers and cargo from land to sea. That, however, will require new types of vessels, harbour facilities and connections to rail and road. The use of very fast vessels will need advanced shipborne and shore-based control and surveillance systems. Fast intermodal flow of goods must be accompanied by integrated information systems indicating the nature and amount of goods, current location, departure and arrival time, packaging, hazards, ownership and many other items of information needed for deciding on optimum transport, which does not necessarily have to be the fastest one, and to allow for dispatching and clearing procedures which do not cause any delay. Handling of goods when being transferred from one carrier to another must be further minimized to save time and manpower.

Authorities and private companies have recently got that message and activities have been initiated in many areas. Research projects have been launched by the European Commission as well as by national sponsoring administrations in parallel with new designs of ships and handling equipment. It seems, however, that there is a lack of integration of all these efforts. There is no global concept available which provides the framework for healthy competition between various solutions so as to finally end up with an optimum solution. Not only an economic and ecological optimum but also an optimum of safety of transport. Which in fact must not differ too much from each other, because the more logically a system is designed the fewer disturbances, i.e. deviations from what is expected, will occur.
Operational Practices

In March 1989, "Seaways", the Nautical Institute magazine, published an article by Rear-Admiral D.J. Mackenzie, Chairman of The Nautical Institute Ship Operational Standards Working Group, which concludes:

"I hope I have been able to demonstrate that the evolution of international commercial shipping has provided a system which is wide open to abuse because there is no easy way to enforce good operating practices".

That was more than three years ago; no improvement has been observed since then. The shipping scene nowadays is characterized by operators just managing capital investment rather than acting as prudent shipowners. The global objective of such management is to maximize profit. There is nothing wrong with that: making a profit is the natural motivation of entrepreneurs. But because shipping must operate against international competitors, every chance to reduce costs is being seized. Even although it is known that safety pays off in the long run, safety budgets are cut to increase short-term profit.

Operational safety always starts with the people doing the job. Therefore, a brief glance at the crewing practice of present-day seafaring will support the assessment of the overall situation. Generally, there are three different methods of manning commercial vessels.

Ambitious manning, which means a sufficient number of well-trained people will handle the vessel. To ensure proper communication between owner and ship’s personnel the nationality of the crew is frequently the same as that of the shore-based management.

Pilot crews consist of the absolute minimum number of sufficiently trained people to take a vessel from one port to another. However, from case to case there might be additional ancillary staff when the workload becomes too high.

"Budget crews" are crews not selected by the company’s personnel department but contracted via international crewing agencies, mostly coming from developing countries and having a low income level. There is no common understanding of operation between the owner and the crew. There is hardly even the minimum flow of information needed to ensure that the owner’s ideas will be conveyed to the ship.

The standards of vessel operation will depend on the quality and commitment of the crew, the ability and confidence of the master and the support of the company. Rules and regulations do not play a major role because these will have no important effect as long as the persons do not have the will and the potential to comply. As long as many company managements together with the vessels’ crews do not fulfill minimum professional requirements, the best ideas for improving the safety of shipping will be in vain. Prudent operation is the essential basis of all additional safety measures. From the safety point of view, there is no way of compensating for lack of good practice.
Spectacular ship accidents have recently caused some public concern. Ship operators, afraid of being held liable for damage caused by pollution by oil or liquid chemicals, have started to work on the situation. The ICS/ISF Code of Good Management Practice in Safe Ship Operation is an attempt to reduce operational malpractices. However, operators are often blamed for just looking for a fig leaf to conceal deficiencies rather than searching for remedies.

Marine Transport Statistics and Investigation of Accidents

Do we really have all data available to sufficiently understand the nature and flow of goods, the motivation and desires of passengers or the distribution and conditions of casualties? No doubt, there is a huge amount of data available describing various areas of marine transport, but does this provide an integral picture? It seems that there are some big gaps in the traffic pattern being recorded by statistical efforts. Even what is available is difficult to obtain because of lack of standardized access to directories and data.

Are we sure that, after an accident, everything really is done to prevent the future occurrence of a similar case? There are certainly considerable differences in the casualty investigation carried out by national bodies, but it seems common to all of them that they lack the appropriate resources for performing the required investigations. The white-bearded captain with a seat on the board of inquiry will contribute his valuable experience but he may not compensate for lack of information required from natural or human sciences, engineering or shore-based management.

A European Marine Transport Safety Concept

In spite of the fact that the quality of ship operation is becoming worse rather than better, it is too early just to give up the struggle. The abolition of European borders by the end of the year provides a unique chance to do something special. Some activities have already been started to harmonize national legislation, but more by working out amendments than by finding a reasonable lowest common denominator. That bottom-up approach, beginning from details, should immediately be supplemented by a professional top-down concept, describing global objectives first. But who should do that work? Existing national safety bodies will certainly need some supranational organization to take the lead. That organization should not just add further administrative people but should use available resources in a competent and effective way. So why not establish a European Marine Transport Safety Board which would act under the umbrella of a European Transport Safety Board ensuring integrity of rules, methods and tools in an intermodal traffic world. The existing bodies dealing with marine safety would send their representatives to the marine transport safety board, where
they would work out the guidelines for all other activities. If we think along these lines we might soon arrive at the idea of a European Coast Guard as the appropriate body for monitoring of performance and the execution of required measures. But that discussion will not be part of this paper. Only some advantages of a European Marine Transport Safety Board are mentioned here.

Defining a European standard of marine safety would be an initial major task. Part of such a standard should be a catalogue of clearly specified objectives and methods resp. procedures and tools for achieving them. As far as possible, road, rail, air and sea traffic should conform to the same basic standards. Besides common cost-benefit considerations, national budgetary situations must be taken into account. Safety of transport should not be dependent on current national fiscal conditions. Therefore some compensation by the European Commission will probably be required for certain countries. Harmonization of safety efforts must go beyond European borders. Worldwide standards are aimed at in the end.

From such a European marine transport safety standard, necessary rules and regulations can be derived. There must be a reduction and simplification of laws. Procedural and technical details should become part of safety notes, always kept up to date by the relevant departments. The time from recognizing a need for changes to amendments to or cancellations of rules must be kept as short as possible. Detailed rules may not go through the full legal procedure. But even then we will end up with a large number of rules and regulations, in many cases being supplemented by recommendations for performance. Therefore, it is now time for advanced information technology to be applied for the development of a decision support system allowing for fast and reliable retrieval of the required information. For the development of such a system, considerable efforts have to be made but if the same system serves within the whole European Community these efforts will certainly pay off.

The range of accepted manning and performance which results in operational practices must be specified Europewide. Quality assurance methods will certainly play an important role, but it has to be ensured that operators and institutions awarding the relevant certifications will establish and maintain the required standards. National administrations must use the instrument of port state control in the same uncompromising way. The frequency and level of safety surveys aboard vessels must not become the subject of competition between ports.

The European Marine Transport Safety Board must comprise a department of shipping statistics, reliably recording data and making these available. The purpose of such data will not be restricted to safety aspects only: on the contrary, shipping economy and logistics will be served simultaneously.

To fulfill requirements of casualty investigation in a really competent way, current procedures must be completely replaced by a European Marine Casualty Investigation Department being part of the Safety Board, too. This department must have the power to obtain immediate access to all relevant information, even with the assistance of the police if necessary. An
adequate budget must be provided to be able to engage experts whenever needed and a
procedure must be established to transform knowledge derived from investigations into
necessary precautionary measures. Where cooperation with universities and other scientific
and professional institutions and individuals is concerned, the Casualty Investigation Depart­
ment must be allowed to go beyond mere accident investigation and analyse the whole traffic
system or modules of it to continuously enhance marine safety. But even where enhancement
does not appear possible, research could lead to lower costs for safety. Economy and safety
are not necessarily contradictory but may well go hand in hand.

Conclusion

Reactions to the Maastricht Treaty recently experienced within some European countries
clearly show that people wish to maintain their national identities and practices. The
establishment of a European Marine Transport Safety Board as a powerful centralized
European institution can be achieved without such conflicts. What is locally available should
be preserved wherever possible and, if necessary, even become reinforced. But at the top
there should be a qualified standardizing and guiding body allowing the whole system to
result in high level European marine safety, thus providing the framework for a healthy
shipping economy.
REVOLUTIONARY MODERNISATION AND SIMPLIFICATION OF RAIL TRAFFIC SAFETY RULES ON NETHERLANDS RAILWAYS

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The Operations Division of Netherlands Railways rewrites all its rules and procedures in an unprecedented way. Some 100 books on numerous subjects are replaced by about 15 new ones in a simple, three-levelled system. Rail traffic safety rules are an important part of this project. They are rewritten beyond recognition, with a modern view on rail traffic processes. Originating from techniques and procedures from the past, they are now based on well-trained staff and present-day signalling. Their size shrinks to about 20 % of the original. The benefits are: easier learning and understanding, simpler signalling, a focus on the human role in rail safety, lower costs and a higher safety level. Profiting from network-wide modern speed-signalling and interlocking, the new traffic rules provide a revolutionary view on rail traffic, which can be used by any other railway. They can serve as a guide for a standardized European signalling system.

1. History

1.1 General development
From the opening of the first public railways, the running of the trains, shunting in the stations, and the duties of the staff in all foreseeable circumstances were covered in a very detailed system of rules and procedures. The generally low level of education and the absence of safety systems made rules and discipline the only protection against accidents.

Traffic rules govern the actions of personnel directly engaged in running trains: signalmen, drivers, guards, shunters, etc. In a wider context, traffic rules also comprise subjects such as training of personnel, carrying out engineering works, safety checks of rolling stock, daily planning, and handling accidents and failures.

1.2 General characteristics of signalling systems
The 1850’s brought interlocking and the telegraph. The combination of both techniques led to numerous electro-mechanical block and interlocking systems. These systems shared a number of characteristics:
- They protected train movements. Safe shunting relied on the experience of, and communications between, signalmen and shunters. Only much later shunting was (partially) incorporated.
- Trains and shunting movements had their own, independent signals.
- The signalling system was a directional system.
- The observations of the signalmen and the knowledge of local signalling and operations by the drivers and other staff remained essential for safety.
Interlocking systems covered only the usual movements. The safety for procedures such as wrong-track running depended on the vigilance of the staff. Failures and mis-handling of the signalling installations could easily lead to highly dangerous situations. Safety gaps in the signalling systems were filled by extensive regulations to limit the risks of human failure. Their limitations determined the traffic rules. Therefore traffic rules usually were drawn up by the Signalling Division.

The risks of human failure were impressive. Forgetting the presence of a standing train, due to not fulfilling a routine procedure, caused Britain’s worst train disaster with more than 200 dead and 200 injured (Quintinshill, 1915).

The interaction between technical improvements and traffic rules produced systems that offered a reasonable level of traffic safety. Developments in electro-technical engineering after the first World War led to compact electro-mechanical interlocking systems that offered a much higher level of safety. They relied less on human actions and covered more aspects of train and shunting movements. However, the signals and traffic rules remained unchanged.

2. Drastic modernisation in Holland after World War Two

2.1 Necessity to choose
World War Two wreaked havoc on the Dutch railways. Netherlands Railways (NS) had to choose between rebuilding with existing techniques or immediate and drastic modernisation. NS chose for modernisation. One example is the abolition of steam traction in 1957, when other railways still built steam locomotives. Another example is the introduction of new interlocking and colour-light systems.

2.2 All-Relay and fail-safe interlocking systems
The first All-Relay Interlocking system became operational in 1949. It was built from very robust components and operated fail-safe. The same components were used for Automatic Block systems. These systems provide a total protection against mistakes by the signalmen. They check automatically all safety requirements before changing a colour-light signal from "stop" to another indication. No action by signalmen is executed by the system, when in conflict with a safety requirement. The only possibility left for human errors by signalmen is when they order a driver to proceed past a red signal.

The NS railway system is now fully equipped with these all-relay interlocking and automatic block systems. Electro-mechanical interlocking and semaphore signals have disappeared. Computerised interlocking is now being introduced on a small scale.

2.3 New colour-light signalling
A revolutionary decision was the introduction of a new, unprecedented colour-light signalling system. After some experiments NS introduced, in 1954, a system that differed totally from existing railway practice. Characteristics of this system are:
- All colour-light signals consist of one red, yellow or green light.
- A yellow or green light can be combined with a lighted number. This number \( x \times 10 \) indicates the speed.
- The system is a pure speed-signalling system.
- Home signals and distant signals show the same aspects; the only difference is that distance signals cannot show red light.
- There is no similarity between the colour-light signals and the night aspects of semaphore signals. This is contrary to the development in other countries, where colour-light signals imitated semaphore signals.
- There are no different signals for trains and for shunting. All colour-light signals apply to all movements.
- All general and local fixed speed limits are indicated by speed signs.
- The speed limit for every route that has a lower limit than the local fixed speed (for example diverging junctions) is shown by colour-light signals.

The NS Automatic Train Control system, introduced around 1965, also gives a speed indication through cab signals.

This new signalling system drew much attention. It still fits all needs of NS. The recently introduced new Swiss high-speed signalling system is a direct derivative.

### 3. Development of rules and regulations

Railways are technical, hierarchical and centralistic organisations. To operate fluently, they needed uniformity. Detailed rules were thought to be the right way to achieve that. A few years ago, NS had about 800 books and binders with rules on highly varying subjects.

NS concluded that the existing system of rules did not fit any more in its organisation and management philosophy.
- The rules were so bulky and complex that they were hardly usable.
- Rules were often made ad-hoc, when something had gone wrong or something new appeared, without a basic philosophy.
- The number of books the personnel had to use kept growing.
- Rules could be so detailed that it was almost impossible to remember them.
- An unappealing lay-out and very formal language made reading difficult, even for experts.
- The professional knowledge and experience of the personnel was in no way reflected in the mass of rules.
- Many rules were not up-to-date.
- Personnel had to find their way through several books on the same subject, to find what they had to do in a certain occasion.
- Personnel was provided with much more "literature", uncoordinated and from different sources, than needed to do their work.
- The way rules were issued conflicted with essential parts of the organisation and management philosophy of NS.

The Board of NS therefore decided to review the current system of rules.
4. Project "Rules-New Style"

4.1 Company-wide project
A company-wide project, named "Rules-New Style" was set up for the review. A set of standards was formulated:
- Rules can only be issued by a manager, and only to personnel in his hierarchical line.
- Rules can not be issued by specialist staff on their own account. They always have to be authorized by the appropriate level of hierarchical management.
- Rules for personnel in another hierarchical line can only be given to the manager in charge of that hierarchical line. The "receiving" manager decides for himself if, and how, he issues or translates those rules for his own personnel.
- Formulation of objectives is preferred over rules of conduct. Rules of conduct are only permitted when necessary for safety or general uniformity.
- For every rule of conduct, it must be proven that it is necessary.
- Rules must be written so that the personnel that has to use them, can understand them. The users must be involved, from the beginning, in the making of the rules.
- Rules must reflect the professional knowledge of the personnel and the training it received for their job. Rules must not regulate every detail.

4.2 Rules-New Style within the Operations Division
After a slow start on a company-wide level, the Operations Division started her own project, aimed at reviewing the rules contained in about one hundred books, used by her own personnel. The Operations Division employs 15,000 men and women (all NS: about 27,500), such as drivers, guards/ticket controllers, platform staff, shunting staff, signalmen, booking-clerks, sales staff and administrative and support staff. The management of the Operations Division decided to have this mass of rules rewritten in just three years.

In their new set-up, rules and procedures will be divided in three levels:

**Level 1** contains company-wide rules, rules issued by other Divisions and external legislation. They are issued only to management and specialists in the Main Office of the Operations Division. There is no formal system for publishing.

**Level 2** consists of a small number of Process Books, each intended for a main part of Operations. All rules, including "translated" rules from level 1, for a Process are brought together in the according Process Book. There will be Process Books for: Sales, Rail Traffic, Planning of Train Services, Goods Administration. The Process Books are destined for all levels of management within Operations. A Process Book consists of one A4-format ring binder. The edition will be a few hundred copies.

**Level 3** consists of Job Manuals. Job Manuals are planned or ready for: drivers; drivers of small or radio-controlled locomotives, shunters, guards, booking-clerks, rostering officers, signalmen, and other groups of personnel whose number reasonably justifies a Job Manual. In practice, all "front-line" staff gets a Job Manual.
The Job Manuals are derived from the Process Books. However, a Job Manual can contain parts from different Processes. A Job Manual consists of one ring binder. The edition varies, according to the number of staff, between 500 and 4000.

Technical, tariff, planning and timetable information is kept separated from the Process Books and Job Manuals. This information will contain no rules of conduct.

5 New set-up for traffic rules

5.1 Level 1: Rail Traffic Rule Book
The Board of a Dutch railway company is obliged to submit a Rail Traffic Rule Book to the Transport Ministry for approval. Before approval, it is scrutinized by the Railway Inspectorate. It comprises four volumes: Trains and Shunting, Engineering Works, Block Systems, and Signal Book, totalling about 300 pages. The edition varies from 2000 to 10.000 per volume.

With full approval from the Railway Inspectorate it will be rewritten beyond recognition. Its size will shrink to maybe 20 pages. Instead of detailed rules, procedures and pictures of every signal aspect, it will contain a short, systematic description of the Rail Traffic Process (basic traffic rules and principles of the signalling system). In its new form the edition will be limited to about 100, to be used by a small number of specialists at NS General Headquarters. It is expected to replace the old Rule Book by the summer of 1993.

5.2 Level 2: Process Book Rail Traffic
This Process Book contains all specific rules and procedures for rail traffic. It is elaborated from the Rule Book and the Railway Act by-laws. It covers all aspects of rail traffic and the safeguarding of its high level of safety, such as:
- Training and examination of traffic staff;
- Rules of conduct for operating the signalling installations;
- Rules of conduct for drivers and other train staff;
- All signals and their meaning;
- Safety checks before departure of a train;
- Rules for the execution of engineering works on or near the tracks;
- Measures in case of accidents and failures; etcetera.

The Process Book deviates totally from its predecessors:
- Every possibility for simplification and modernisation has been used;
- Different solutions for look-alike problems have been unified;
- Complex procedures are replaced by flow-charts;
- Rules for little used possibilities have been abolished;
- Unnecessary detail in rules and procedures has been abolished;
- Rules have been written as much as possible as objectives instead of specific conduct, giving local management and personnel the possibility (and responsibility!) to find the best and safest local solution;
- It is written as a guide for present-day, well-educated and well-trained staff.
- It is written in accordance with present-day knowledge on education, presentation and communication.
The Process Book Rail Traffic will be used by all management-levels in the Operations Division. It will not be supplied to the personnel itself (although they are free to read and use it). The General Manager of the Operations Division is responsible for it. He sends it to the General Managers of other Divisions (Maintenance of Way, Electrical Engineering, Mechanical Engineering etc.). They must live up to the Process Book, but they are completely free in the way they choose to have their own personnel to act according to the Process Book. If they would like to rewrite it, they are free to do so.

The Process Book replaces more than 15 different books and parts of books, totalling more than 700 pages. This includes the old Rule Book, mentioned under Level 1. The Process Book will have about 100 pages of text in a lay-out with much white spaces, plus pictures and meanings of all signals. It fits into one A4 ring binder. The edition will be about 500.

5.3 Level 3: Job Manuals
Job Manuals are compiled for all personnel in direct operations. A Job Manual contains only the essential minimum of rules and procedures for that job. The Job Manual for drivers is an A5 ring binder with 55 pages of text and 100 pages with signals. This small and thin manual contains all rules and procedures a driver really needs to do his job. In the past, he had more than 8 thicker books for the same job!

Respect for the professional skills of Operations personnel is essential. Not everything a well-trained railwayman knows, has to be written down. Basic knowledge, routine actions and daily practice must not be included when they are not necessary rules of conduct. Training to do the right things right is much more effective.

5.4 Technical information
Besides these three levels of rules, there are new technical manuals, describing the control of rolling stock, control panels for signalling, opening of bridges etcetera. These manuals only contain technical information. Contrary to old times, they are written by the Operations Division itself. If Operations should ask a technical Division to write them, that Division must strictly fulfil the requirements of the Operations Division.

For each type of locomotive and multiple unit there is a Guide. A Guide contains a short operating instruction and a number of flow-charts to trace and remedy small failures. Guides are present in all cabs and are supplied to all drivers qualified for a certain type of rolling stock. Similar guides will be made for each "desk" in a signalbox, containing all relevant information for just that desk.

The new system of rules is to be completed by an automated data-base system providing all information for making up trains, such as braking percentage, maximum speed for the available brake power, maximum weight or length, etcetera.
5.5 Education and training
Rules-New Style lays much emphasis on training. Between the Project Rules-New Style and the Central Training Institute of NS there is a close cooperation. Information not belonging in the rules, but necessary or desirable to perform well in a job, is recorded in the Education Documentation. This information is integrated in the training courses.

6. New system of traffic rules

6.1 Necessity to rewrite the traffic rules
Rewriting the traffic rules meant a confrontation with rules that rooted in techniques and procedures from the start of the century. There was a total mis-match with the present organisation, modern safety systems and future developments. Total renewal was essential. The now completed modernisation of signalling systems, which started 40 years ago, gave great opportunity a drastic renewal.

6.2 On-shore and on-board processes
A modern railway traffic system consists of two main functions:
1. Setting of routes, according to the daily planning, by signalmen. Their basic work has been reduced to pushing buttons or handling a keyboard. The fail-
safe interlocking system performs all safety checks and sets the signals automatically, but only when all safety requirements are met. The setting of routes includes:
- setting a route plus issuing an order to drive carefully at any place;
- giving an order to pass a red signal during signalling failures;
- preventing setting of routes in case of danger and during engineer's possessions.

2. Regulating speed, according to the signals and the timetable, by drivers. The NS speed signalling system permits a driver to follow the speed as indicated by the colour-light signals, speed signs and automatic train control, without prior knowledge of routes, speed limits or braking distances (only for limited sight conditions, he still must qualify for road knowledge), unless a signalman issued an order stating otherwise. The driver can be assisted by an attendant, who performs specific safety tasks. The attendant can be the guard of a passenger train, a shunter on a goods train, a platelayer on an engineering train or another qualified person.

In the new Process Book these two main functions are totally separated in:
- the "on shore-process": setting of routes; and
- the "on board-process": regulating speed.

Essentially, this is the rock-bottom basics of the railway system. Only a minor part of rail traffic, on goods-only branches and in yards, is not protected by signalling. For these "unprotected" areas, the same separation has been made. Within the general principles of the Process Book, it is the responsibility of local management to organise the safety precautions and procedures in these areas.

These functions are the nucleus of the Process Book Rail Traffic. The separation follows the logical organisation of a railway system, and the duties, limits and responsibilities for management and staff are immediately clear. Furthermore it is a radical departure from the style of the old rules, written down integrally from a purely technical point of view.

6.3 Support functions
An important support function is checking the consist of a train and the technical condition of its vehicles before departure. The rules and procedures for this function have their own capital in the Process Book. In the near future all relevant technical information shall be available in a database-system, replacing about 6 different publications. The aims of this support function concerning safety are twofold:
- Preventing the running of defective vehicles in a train;
- Issuing the driver with a speed limitation order when a train does not meet minimum speed or braking requirements. The aim is to prevent speed limitation orders by prohibiting the running of trains that do not meet requirements, even if it leads to higher costs. If accomplished, this is another simplification of the traffic rules.

Other essential support functions are:
- Mental and physical ability, training and examinations
- daily planning of train and shunting services (opposed to long term planning
and rostering of crews and rolling stock);  
- Planning and safety measures for engineering works;  
- Emergency measures and accident research.
These support functions make up the other capitals in the Process Book.

6.4 Farewell to the past

In the new Process Book Traffic Rules NS says farewell to numerous procedures and principles from the past. Many are common for railway systems elsewhere.
- All differences between trains and shunting movements have disappeared, except the safety and consist check before departure.
- Differences between trains made up from normal rolling stock and trains made up from engineering stock ( tampers, road/rail-vehicles etc.) have disappeared.
- Responsibilities are centered on two officials: the signalman and the driver.
- Duties of other train staff are integrated in the "train attendant".
- The title of Chief of the Train, stemming from the handbraked trains of the past, and the highest official on a train, has disappeared.
- Platform staff (the man with the red cap) has no traffic safety duties left over.
- Many precise rules of conduct are replaced by an instruction for local management to make local rules, and so giving up network-wide uniformity on e.g. passing safety information on changes of shifts, fixing yard limits for shunting, presentation of daily planning, safety procedures in unsignalled yards, division of tasks between driver and train attendant etc.
- Traffic rules are now laid down by the Operations Division, instead of the Signalling Division. The Signalling Division must comply with the requirements laid down by Operations and must adapt itself to demands, made by Operations to simplify rules and procedures, and also the signalling system itself.

7 Results of Rules-New Style

7.1 Job Manual for drivers
As a test for practicability, the Project Rules-New Style started with the Job Manual for drivers, thought to be the most difficult one. It was published one year ago. The results are highly remarkable. This Manual is an A5-sized ring binder with 50 pages of text (and a lot of white spaces) and 100 pages with signals. It replaces about 8 books with about 600 pages of rather small printed text. It was received with much enthusiasm by the drivers. The fact that groups of drivers were involved from the earliest beginning contributed considerably to its success.

7.2 Process Book Traffic Rules
Six months ago work on the Process Book started, and it is almost ready now. It is submitted for comments to the managers who have to use it. In the past months, a total re-invention of the traffic rules was laid down. The Process Book will be ready for printing by the end of the year. It does not have more than about 100 pages of A4-format. About 15 different books with about 600 pages of text, totally or partially filled with traffic rules, will be replaced.

The rules for the on-shore and on-board functions in signalled areas fit onto only 14 pages. The main part of the traffic rules (on-shore and on-board processes) takes only 32 pages. The rest is taken up by the supporting functions.
7.3 Rail Traffic Rule Book  
Work on a new Rail Traffic Rule Book (= level 1) has not been started yet. The planning is, that it can be submitted for approval by the summer of 1993.

7.4 Guides for rolling stock and signalling  
Most Guides for rolling stock have been published in eighteen month's time. Work on Guides for signalling installations started a few months ago. The presence of more than 100 different "desks", all with their local peculiarities, makes it a more difficult job than the Guides for rolling stock.

7.5 General accomplishments  
The drastic and unprecedented renewal of the traffic rules has many interesting effects.
- The new rules now describe how people work in reality. In spite of the drastic changes, they do not have to adapt to new routines. Only the Signalling Division has some problems to adapt to its new role.
- The clear structure of the new rules presents on forehand solutions where in the past there were unstructured ad-hoc decisions.
- The new rules demand professionalism and responsibility from everybody, instead of acting as a scale for measuring petty infringements of strict, but complex and badly remembered procedures.
- Rules changed from dull, unreadable books to a usable aid and tool for personnel and management. Interest in it has been aroused by a publicity campaign.
- The total size of the rules has shrunk almost unbelievably, by more than 80%!
- The drastic simplification is big plus for training. Less rules means less to learn (and less that can be forgotten), a reduction of necessary training and therefore a reduction of training costs.
- The drive to simplify the rules gave birth to a reduction of the number of different signals, and therefore, in the long run, a reduction of signalling costs. For NS this reduction was limited, because of its already very simple speed signalling system.

8. Safety effects of the new traffic rules  
Railway traffic rules always aimed at the safety of rail traffic. The question if the new, drastically simplified and shortened rules could influence safety, is therefore relevant.

NS expects a reduction of the number of accidents. Many accidents originate from human mistakes, like reacting too late on a signal. More and stricter rules do not change that. On the contrary, unclear, complex and non-uniform rules can be a source of mistakes, and therefore a source of accidents.

Years of doing the same work can create routines that deviate from the official rules. This can cause risks which can be prevented when local management and personnel understand these risks and have to look for practical and safe solutions for their local situation. This shifts responsibilities from personnel, falling in a trap through working on routine, to management, that has to prevent such traps. Local management can no longer hide behind the rules, but has the freedom and duty to
look for solutions without being bound by strict network-wide rules. This should lead to a reduction of accidents, mostly during shunting. Shunting accidents cause much more damage than train crashes!

The freedom of local management to decide on more aspects of rail safety makes a reporting system necessary, so top management can judge their policy (just like other aspects of their job, like finance and personnel affairs). Thinking about such a system is still in its infancy within NS. It is likely, that the future will bring a rail safety auditing system based on ISO 9000 f.f. Quality Standards or another usable system. Such a system would fit neatly in developments in other area’s, such as Safety and Health at Work, and the future role of the Railway Inspectorate. It would be another contribution to a higher level of rail safety.

9. The new Traffic Rules from a European point of view

The European Community obliges its Member-States to open their railway networks to third parties. In the German-Belgian-Dutch region of Aachen-Liege-Maastricht drivers must already have through knowledge of three totally different systems of signalling and traffic rules. A drastic simplification of rules and signalling as realised by NS could lighten such a burden enormously.

The separation between on-shore and on-board process in the new traffic rules also permits the separation between Infrastructure and Operations, as has been required by the European Community.

The UIC is working on the European Train Control System (ETCS). ETCS defines an interface for train control between a train and track-side installations and gives speed indications to the train and its driver. The new NS traffic rules are fully based on speed signalling, and ETCS can therefore without real problems concerning the traffic rules be introduced on NS.

The UIC is also working on standards for a European interlocking system. This new system can be expected to emphasize on speed signalling. The new, very simple NS traffic rules and speed signalling could serve as a model for the rules and signalling needed for a standardised system. Its simplicity could result in a substantial reduction in the necessary hardware and engineering and the training of personnel with the additional bonus of a higher safety level.
10. A challenge

NS replaces more than 150 years of steadily developing traffic rules by something totally new and unprecedented. For a railway system, used to very long life-cycles, such a change is a true revolution. NS can use its advantage of completed modernisation of signalling systems to the utmost to introduce a system of traffic rules that fits the near and the far future.

The national railways in the European Community will become European railways in a rapidly changing technology and transportation landscape. To them, the challenge is to look at their own traffic rules with the same eyes as NS is doing now. NS is confident that, if other railways should do so, they can attain the same positive results as NS, and at the same time realise savings of many hundreds of millions of guilders or even more, and also attain a higher level of safety.
Abstract

Flight Simulators have long been used as instruments for the improvement and advancement of aviation safety. The Delft University of Technology and the National Aerospace Laboratory are two institutes in the Netherlands which conduct research using flight simulators. The Delft University of Technology will continue to investigate fundamental issues related to simulation, motion, and navigation systems technologies through a dedicated "Basic Research Simulator". These will include new techniques for hydraulic motion system control and for motion drive laws, mathematical modelling of flight and surface vehicles, and evaluations of man-machine interactions in future cockpit environments.

Operational aspects of aviation safety are of prime concern to NLR. In particularly, investigations into harmonized air traffic control (ATC) systems will be investigated. The integrated design and evaluation of future systems is possible by networking together three primary facilities of the NLR, namely the NLR ATC Research Simulator (NARSIM), the Research Flight Simulator (RFS/NSF) and the research aircraft equipped as an Avionics Research Testbed (ART).

Combining the fundamental research activities of the Delft University of Technology and the applied research activities of the National Aerospace Laboratory will ensure that future aviation scenarios are validated in a realistic simulation environment.

1. INTRODUCTION

Increasing global emphasis on air-transportation safety

Society and the transportation industry are placing severe and new demands on the safety, quality and environmental integrity of future transportation systems. Increasing international competition in the air transport industry, coupled with the shifting emphasis on commercial rather than defense technology development, are all catalysts in the quality trend.

Transport vehicle systems and the services which they provide are expected to be a key issue in guaranteeing prosperity to nations. The transportation industry is thus faced with the logistical problem of meeting capacity with demands while simultaneously ensuring a high standard of safety. Furthermore, growing environmental concerns will increase the pressure on optimizing the flow of traffic.

Maintaining a high level of safety is one of the benefits offered by flight simulators to the air transport industry. The widespread use of simulators, from part-task trainers to full "zero-time" flight simulators, makes these systems cost-effective and environmentally sound alternatives to in-flight training. Due to increasing global traffic paralleled with a high demand on safety, the control features of future vehicles must be optimized with respect to the limited capabilities of the human operator. This optimization process is necessary in the design of the vehicle. Vehicle-operator interactions can best be evaluated in a moving-base simulator.
A research simulator can serve as a testbed for developing simulation technologies which can then be applied in a more specific way to crew training simulators. Secondly, the research simulator can provide an ideal environment to evaluate pilot performance and the interaction between the cockpit and the human controller. On the other hand, simulation technology must be furthered in order that the most meaningful design data can be derived from evaluations in simulators. The fidelity of the flight simulator depends on both the hardware and software in their ability to recreate the instantaneous “real-time” aircraft responses to the pilot inputs. The end result must be that the simulator’s physical cues must also match those felt in the aircraft while performing the same maneuver. Meanwhile, both the simulator hardware and software must make compromises due to the inherent mechanical limitations. It is important that pilots do not learn to adapt to these inaccuracies and, hence, learn to “fly the simulator”.

Developing new strategies to optimize the match between simulator and vehicular cues is one of the primary goals of the Delft University of Technology. In the near future, the “Basic Research Simulator” will become operational. This device, currently under development and expected to begin operation in 1994, will serve as a platform by which the fundamentals of simulation will be researched. The key issues related to affect aviation safety which will be addressed by this project are discussed in Section 2 of this report. The tools by which this will be carried out are described in Section 3.

A research simulator can also provide a vital tool for developing fully integrated cockpit systems. Whereas the Delft University of Technology is concerned with the fundamentals of flight simulator control and cockpit interfaces, the flight simulation department of the National Aerospace Laboratory focuses on assessing integrated aviation systems to ensure their operational safety. Section 4 of this report describes significant contributions made by the NLR in simulation research, while Section 5 discusses the NLR simulation facilities.

2. FLIGHT SIMULATION RESEARCH AT THE DELFT UNIVERSITY OF TECHNOLOGY

The Delft University of Technology has played an important role in flight simulation research for over two decades. Friction-free hydrostatic bearings, which are now applied to all motion systems worldwide, were developed by the DUT [ref. 1]. A three-degrees-of-freedom research simulator was used as the development platform for these [fig. 1]. Several motion drive algorithms were also developed here [ref. 2]. This simulator has served as a vital tool for the development and evaluation of hydraulically-driven sidestick controllers, and for fundamental work on human motion perception.

The three-degrees-of-freedom flight simulator had provided twenty-three years of service as a valuable research tool, but was built on 1970’s technology. In response to the increasing demands on the performance of aviation systems, the Delft University of Technology has begun a new phase in fundamental research utilising simulation equipment. The need to evaluate various candidate cockpit environments in the presence of highly accurate motion and visual cues has led to the development of a specialized and advanced simulator for fundamental research - the Basic Research Simulator, or “Baresim”. This tool will thus enable research into simulation, motion and navigation technologies in a way that is otherwise not possible [ref. 3].

There are two main functions of the Baresim research program: First, research will focus on the development of highly advanced technologies particularly in the areas of simulation modelling, hydraulic motion system control, and navigation systems integration in real-time simulation. In the process, improved hardware and software for simulation will result. Secondly, the facility will serve as a ground-based “test platform” for evaluating human pilot performance under simulated conditions which very closely match reality.
The Basic Research Simulator (Baresim) will focus on three areas of technology. These are:

**Motion:**
- Control techniques for hydraulic motion systems
- Simulator motion drive algorithms
- Human visual/vestibular system interactions in motion perception

**Simulation:**
- Development and evaluation of new simulation-related technologies, such as for visual display systems, control loading systems, computer networks. Spin-offs would extend beyond the pure simulation industry.
- Mathematical modelling of aerospace and surface vehicle dynamics, including (aero)elastic

**Navigation:**
- Real-time simulation of navigation system errors
- Development and evaluations of four-dimensional navigation systems
- Cockpit man-machine interface research

A wide range of research applications will be possible with the Basic Research Simulator. These will in turn provide significant support to improving safety, whether through improving the quality of simulators or as design inputs for aircraft cockpit systems design. An artist’s impression of Baresim is shown in Figure 2.

### 2.1 MOTION CONTROL RESEARCH

New motion control strategies will provide the building blocks for the Baresim motion system, as well as for future commercially-available systems.

First, advanced mathematical concepts will be produced for the control of simulator motion systems and their individual elements, the hydraulic actuators. The motivation for this is to produce new strategies for high-precision motion system control which are also non-existent in current commercially available applications. The development of advanced motion control mathematical techniques are necessary in order that the simulator may precisely follow motions described over a wide frequency range. Current motion control technology is limited in its ability to fully compensate for mechanical deficiencies and dynamic lag. In the field of robust multi-variable control, much effort is devoted to the development of new linear theories (e.g. $H_{\infty}$, $\mu$-analysis and synthesis), both in modelling as well as in control design [ref. 4].

Then, the concept of multi-variable control of the six-degrees-of-freedom motion system will be addressed, also with new techniques in mind. This will consider the coupled synergistic motion system of the simulator. The findings of these will guarantee that the dynamics of the simulated vehicle are sensed by the simulator pilot, and not the dynamics of the simulator itself. These techniques, when applied to commercial simulators, will reduce the sensation of false cues caused by deficiencies in the mechanical properties of the motion system.
2.2 SIMULATION TECHNOLOGY RESEARCH

The realism of simulation depends considerably on the accuracy of the mathematical model, along with the ability of the hardware to recreate the flight deck environment in real-time. The system models can be either based on empirical relations, or on values determined by identification of the system parameters. Numerous techniques for the modelling of flight vehicles are being developed or ameliorated so that simulation realism is significantly improved. Secondly, simulation technologies will be used to support research necessary toward the understanding of human pilot interactions with the cockpit environment.

a) Real-time simulation of aeroelastic effects:
Current flight simulators are unable to simulate deformations of the aircraft structure. These flexibilities, interacting with pilot control inputs and turbulence, can affect the behaviour and stability of aircraft, especially large transports [ref. 5]. The inclusion of such effects, for example, would considerably improve the realism of simulation. The accurate inclusion of the destabilizing effects of aeroelasticity will provide simulation models with all of the motion cues sensed in the real aircraft. The ability to reproduce these high-bandwidth cues enables fundamental research into pilot modelling methods; i.e. the mathematical representations of human pilot behaviour.

During the coming four years (beginning in September 1992), a comprehensive research program will address the problem of the mathematical modelling of aircraft structural flexibilities for real-time simulation. Since these effects do not exist in current simulation models offered commercially, it is necessary to develop techniques suitable for computation in real-time. This will involve developing aerodynamic transfer functions based on integrated Computational Fluid Dynamics (CFD) interacting with the structural properties derived from Finite Element Methods (FEM). This integrated approach would offer a new means of computing mechanical responses of aircraft structures to static and also to non-homogeneous loads. This modelling will therefore include inertial and aerodynamic coupling. Note also that in order to apply the aeroelastic models, it is necessary to also develop methods of generating simulator motion system responses uncorrupted by mass-induced dynamic lags or other hindering effects. These were described above.

The development of highly accurate real-time aircraft models which include aeroelasticity is useful for both research simulators, such as Baresim and the NLR facilities, and also for commercial pilot training applications.

b) Advanced aerodynamic models of rotorcraft:
Modern rotorcraft modelling techniques treat the main rotor blades as separate lifting surfaces with discretised spanwise segments. Flow computations for each of these blade elements is summed for each lifting blade at a high frequency to account for variations in blade forces throughout the rotational cycle. What is still lacking is the modelling of the main rotor wake on the helicopter body airflow, and the interactions with the tail rotor. Furthermore, deformations of the usually highly-flexible blades need to be accounted for, as do the reactions of the entire vehicle during flight through unsteady (turbulent) flow. Modelling of rotorcraft in the vicinity of the ground also needs much improvement due to the extreme complexity of the flow characteristics. These properties must be included in future rotorcraft simulation models to ensure similarity with actual flight.

The Delft research flight simulator will provide the means for developing and evaluating such models. Experience with aircraft parameter identification techniques will clearly support this research.

c) Identification of human visual/vestibular motion perception qualities:
The identification of human motion perception thresholds and vestibular system dynamics is necessary for the design of simulator hardware and software. The causes of disorientation may also be investigated, as well as low frequency ocular-vestibular interactions. Note that it is essential that parasitic motions be absolutely minimal so that erroneous signals are not sent to the vestibular system. In the case of the Basic Research Simulator, this is accomplished through the use of advanced control laws to drive a platform with low mass and inertial properties. A low centre of gravity further reduces the need to compensate for parasitic motions.

Flight simulator visual display systems provide a tremendously realistic stimulus to the pilot, a sensation which can often be mistaken for low frequency motion. The bandwidth of the stimulus strength depends on, among other factors, the field-of-view of the image. Research simulators have been used extensively to study visual perception [ref. 6], and this will be continued within the Basic Research Simulator programme.
d) Motion Drive Algorithms
New techniques for matching the simulator-sensed motion and visual cues with those experienced in the aircraft will be developed. New approaches based on identifying aircraft responses during flight-critical maneuvers [ref. 7] will lead to motion filters tuned by objective mathematical techniques rather than by (present-day) subjective pilot evaluations. Motion drive parameters will be optimized with input from the research described above, namely human visual/vestibular motion identification.

e) Basic research into display presentation formats:
This area combines aircraft systems research with human factors studies in that the man-machine interface is considered. The fundamentals of display presentations are of considerable importance in meeting two contradictory objectives; namely to present all of the information that is necessary to control and monitor a given task, while simultaneously avoiding display clutter. For example, comparing analog displays with digital displays. Object-oriented factors such as the shape, size and colour need to be addressed. The dynamic characteristics of these objects need also to be studied under realistic conditions representative of the real vehicle environment.

f) Research into sidesticks
The use of sidestick controllers is increasing in the aerospace industry as these systems readily lend themselves to stability-augmented digitally-controlled aircraft. However, the man-machine aspects of these controllers need to be further understood in order to evaluate which type of controller and related algorithms are best suited for a specific task.

Several types of sidestick controllers are available, including the non-compliant (rigid) force sensitive type, position sensing spring-loaded sticks, and servo-controlled sidesticks. Unlike the traditional yoke control column which feeds back aircraft control stiffness to the pilot, the sidestick, a pure signal generator, inherently has no such provision. The control force sensation becomes an open loop function, relying on the visual and vestibular systems for feedback. The servo-controlled sidestick pursues to close this loop and to even provide additional information to optimize the performance in a specific task. A servo-controlled sidestick can be considered a manipulator in which the stick force can be made independent of position, providing the possibility to use it as an active controller. For example, the performance of a tracking task can be improved by causing the stick to move laterally in the same sense as the aircraft roll. Pilot arm sensations naturally resist this motion, thereby restoring the vehicular motion.

Various signals can be presented as stick position, such as the aircraft roll angle, roll velocity, roll acceleration, or combinations of these [ref. 8].

2.3 NAVIGATION SYSTEMS RESEARCH

a) Mathematical modelling of radio-navigation signal errors:
The integration of on-board navigation systems may significantly improve their integrity, reliability, accuracy and maintainability, as well as reducing the number of stand-alone nav aids. The accuracy of such integrated systems is commonly calculated from the statistical model of each individual sub-system. It is of concern to the aircraft avionics designer, the pilot, and regulating authorities how the pilot (or the auto-pilot) will react to worst-case navigational errors. This is of particular importance during the landing phase.

A flight research simulator provides unique opportunities to explore the MMI aspects of these situations under fully controlled and highly realistic, reproducible conditions. Navigation equipment can be modelled by several means, from low-level tracking loops, up to the high-level integrated systems such as GPS (Global Positioning System), or MLS (Microwave Landing System).

Candidate radio navigation system research topics for the Basic Research Simulator Programme include the following:

i. Optimum tracking loop design in radio nav aids for maneuvering aircraft

Radio navigation is based on measuring the ranges and angles with respect to a number of transmitters at well defined positions. The received radio signals, however, are susceptible to atmospheric and thermal noise and interference from other signals.
ii. Pilot reactions to infrequent, yet large and realistic navigation errors

Noise and interferences in navigational equipment affect the tracking performance of flight vehicles. These disturbances have many different sources, making it rather difficult to determine the worst-case conditions. Such worst-case conditions can be introduced into the piloted (or automatic control) loop to analyze their effects.

iii. Multi-path effects on position with GPS and MLS and attitude determination with GPS in the approach phase

The increasing feasibility of Navstar/GPS and MLS will make these among the most popular radio-navigation systems in the foreseeable future. Whether these systems are accurately secured against the infiltration of unknown signals (reflections, interference from other sources, etc.) under all conditions, including landing, is yet to be determined.

In an MLS scenario, aircraft may follow curved trajectories during the approach. The signals can be temporarily blocked by buildings, ground equipment, even by other aircraft maneuvering on the ground in the proximity of the transmitting beacon. In an approach guided by GPS information, however, the signals can be influenced by geographic features such as mountains, or by temporary eclipsing as aircraft at higher altitudes pass between the GPS satellite and the receiving aircraft. It is valuable to investigate the influence of these factors on the performance of vehicles, and the reactions of pilots to the fluctuations of the signals during the control task.

It is possible to model the interference functions with the visual scene data base model, and to interactively program their effects with the flight simulation. In this way, the effects of changes in topography and airport layout on these signals can be suggested.

The transition between one signal to another should also be investigated, as well as the reaction of pilots to sudden changes in these presentations. For example, if a pilot flies the initial approach using GPS information, then switches to an MLS system for the final approach, the system should indicate and allow correction for any differences.

GPS, as well as Glonass, give excellent position information, as well as highly accurate attitude determination [ref. 9]. In this scenario as well, there are risks of signal blockages, interferences, reflections, and other factors which would deteriorate the signal quality. Additionally, it is important to understand how the system will recover after a serious signal disturbance.

iv. The verification of approach dynamics limits for given radio-navaid dynamic tracking specifications

Poor signal conditions may limit the allowable dynamics of an aircraft when path-following errors are complex. It is necessary therefore to confirm the theoretical analyses in special cases, such as flight through heavy turbulence when aircraft dynamics are a maximum. The resulting excess in the accuracy limits should be determined. These results can be effectively determined in a flight research simulator.

b) Evaluation of Four-Dimensional Navigation Systems

Due to the increase in air traffic, the demand for tighter control of commercial aircraft is becoming more critical. Current Air Traffic Control (ATC) procedures provide control over very short time spans, due to the lack of accurate information regarding the future trajectories of flight vehicles. This results in a new set of constraints every few minutes, which increase with the volume of air traffic.

Since trajectory information is present in the aircraft Flight Management System (FMS), such knowledge by ATC would provide control over greater time spans. However, information transfer between the ground and air would also be necessary in a negotiative process to establish the trajectories of multiple vehicles. The negotiation pursues suitable trajectories, in view of optimum performance, shortest routes, weather conditions, proximity to other aircraft, and runway utilization [ref. 10]. As a result, four-dimensional (4D) navigation arises. The operation of aircraft in critical time and space conditions, and hence the presentation of useful and accurate 4D information to pilots, requires considerable attention. However, before 4D navigation can be accepted in flight operation,
fundamental research on the presentation of 4D trajectories and on pilot behaviour in 4D supervisory control tasks needs to be evaluated.

The research flight simulator provides an ideal environment for the optimization and evaluation of 4D navigation displays. A candidate display is called the "tunnel-in-the-sky" in which the pilot guides the vehicle through a passage that is presented on the EFIS in a three-dimensional picture [fig. 3]. The tunnel, generated with the help of the FMS, represents the vehicle trajectory required by ATC. The tunnel-in-the-sky requires the pilot to "fly" the navigation information provided by ATC. However, the low natural frequencies associated with the control of large transport aircraft in tight lateral and vertical constraints poses difficulty to the pilots. The presentation of predicted flight path information serves to provide a high-order damping cue to the pilot, thereby reducing the overall workload and improving the system handling qualities.

3. FLIGHT SIMULATION RESEARCH FACILITIES AT THE DELFT UNIVERSITY OF TECHNOLOGY

The current flight research simulator of the Delft University of Technology has been in service for over two decades. During this time, this system has served as a useful tool for the development of hydrostatic-bearing motion systems, motion drive laws, the development of aerodynamic models, and for evaluating cockpit systems. Due to growing demands for research requiring the use of Delft simulation facilities and faced with limited capacity, the Delft University of Technology has begun the design and technical development of the Basic Research Simulator (BARESIM) facility. The design of BARESIM has precipitated from the foreseen needs of the flight simulation industry, particularly in improving the quality of the many cues perceived by pilots. This simulator will coalesce many new technologies from the aerospace, mechanical, and electrical sciences to create a system which is notably different from present-day simulators.

Several features of the BARESIM configuration have stemmed from the requirements to investigate specific areas of interest which are, or will be of merit to the next generation of vehicle simulators.

Baresim's motion system is driven by six linear hydraulic actuators with a stroke of 1.25 metres. Double-concentric pistons with friction-free hydrostatic bearings are applied. This design principle is also incorporated in the new NLR simulator since it provides a symmetric piston surface on both sides of the actuator rod. This in turn optimizes the servo valve dynamics and thus provides highly accurate motion system response.

Baresim will feature a generic and reconfigurable cockpit capable of representing various types of vehicles. A two-seat side-by-side transport aircraft can be represented in the front, or a single place research vehicle in the rear workstation for helicopters, automobiles, etc. The floor is located beneath the semi-triangular structural frame in order to lower the overall centre of gravity position of the moving flight deck platform.

This frame is to be built from an aluminum-polymeric material, either ARALL (Aramid-reinforced Aluminum Laminate), or GLARE, which uses glass fibres. The weight and mass moments of inertia of the platform frame will be less than one third of the same for a conventional steel frame. The flight deck equipment of the Basic Research Simulator will provide the following possibilities:

- Simulation of various types of vehicles (incl. aircraft, helicopters, surface vehicles) and quick configuration changes [fig. 4].
- Accurate representation of high-frequency motions due to a highly stiff flight-deck design.
- User-programmable static and dynamic properties of hydraulically-driven controls in yoke and sidestick arrangements [fig. 5].
- Single or dual-pilot operations possible due to a three-channel visual display system (left, front, right monitors).
- Programmable Electronic Flight Instrumentation System (EFIS) "glass cockpit", presented on five screens abreast. The display generation system, developed in cooperation with the NLR, permits easy programming and modifications to all of the display properties.
4 SIMULATION RESEARCH AT NLR

4.1 GENERAL

The National Aerospace Laboratory NLR is the central institute in the Netherlands for aerospace research. Its principal mission is to support the national aerospace industry, operators and governmental agencies in the design, development and certification of civil and military aircraft and helicopters, and to assist operators in the operational use of these systems. The NLR has at its disposal both qualified personnel and large R&D facilities such as wind tunnels, materials testing facilities, laboratory aircraft, flight and air traffic control simulators, aircraft instrumentation systems and a very powerful computer infrastructure. All these facilities are regularly updated to meet all types of customer's needs. Recently, NLR facilities have been effectively used in the successful development and certification of the Fokker 50 and Fokker 100.

NLR has one of the few high-quality modular R&D flight simulation facilities in the world. The facility has been in operation since 1974 for Dutch and foreign customers. Projects in which the simulator has played an important role include pilot-aircraft interactions and such related topics as flying and handling qualities research, man-machine integration, advanced flight control and displays development, operational procedures and avionics integration.

For research in the civil and military area, NLR's Flight Simulation Department has at its disposal simulation models of different types of aircraft. This diversity of models, representing different categories of aircraft, allows to do research with the most suitable type of aircraft, ranging from small business aircraft to wide-body transports. The aircraft models that are available for simulation on NLR's Research Flight Simulator are:

- a small business type of aircraft, with characteristics and handling qualities comparable with those of the Cessna Citation 500;
- a medium-size transport aircraft, having the characteristics and handling qualities of the Fokker 100;
- a large wide-body transport aircraft, with handling qualities and characteristics of the Boeing 747;
- a fighter aircraft, with characteristics and handling qualities of the F-16 A/B "Fighting Falcon".

Currently under development are:

- a small propeller-driven aircraft, with characteristics and handling qualities of the Fairchild Metro II;
- a generic helicopter simulation model based on the blade element method and adaptable for different types of helicopters.

On a regular basis, qualified pilots are invited to 'fly' the research flight simulator to validate the mathematical models of the applicable aircraft. This guarantees the quality of the simulation models and the realism of the simulation.

The different types of aircraft models available and the modular set-up of equipment and software allows for a large flexibility and enables NLR's Flight Simulation Department to fulfill a large variety of requirements of the different contractors and different types of research subjects. Some examples of studies that have been and will be performed with NLR's Research Flight Simulation facility are highlighted in the next paragraphs.

4.2 THE MICROWAVE LANDING SYSTEM (MLS)

For more than four decades the Instrument Landing System (ILS) has been in use around the world to help pilots land safely when visibility is poor. Drawbacks inherent to ILS such as frequency congestion, FM radio interference and siting constraints have been felt increasingly. Studies of the International Civil Aviation Organization (ICAO) have led to the development of the Microwave Landing System (MLS), which is expected to replace ILS as the standard landing aid gradually from the end of the 1990's. In contrast to ILS, MLS provides guidance in a large area, and enables curved approaches to be flown in addition to the usual straight-in approaches [fig. 6].

The capacity of some airports equipped with ILS is lower under Instrument Flight Rules (IFR) than under Visual Flight Rules (VFR), when pilots can fly curved approaches that avoid conflicts with aircraft approaching nearby runways. The use of MLS would enable pilots to fly curved approaches under IFR also, improving the capacity
of these airports when visibility is poor.

NLR has been carrying out research into the operational use of MLS, under contract to the Netherlands Department of Civil Aviation (RLD), the US Federal Aviation Administration (FAA) and other organizations. Using its Research Flight Simulator (RFS) NLR has evaluated curved path approaches, interception procedures and departures [ref. 11-12]. Pilots from various airlines and agencies took part in the projects, where the RFS emulated a Boeing 747-200 wide-body aircraft. Both the actual paths flown with the RFS and the pilot's opinions on the procedures they were instructed to follow were recorded, in order to determine acceptable parameters of procedures.

In addition to the research with its flight simulator, NLR carried out MLS flight tests, using its Fairchild Metro II laboratory aircraft at the airports Gatwick, Cardiff, Manchester and Heathrow. A programmable Electronic Flight Instrument System (EFIS) was fitted in the aircraft, showing calculated guidance signals in the layout of conventional navigation instruments. Interception techniques and the use of glide path angles of 4 and 6 degrees were evaluated as well as computed guidance, where the MLS transmitter was positioned at a large distance from the runway centre line, at a parallel runway.

4.3 TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS)

With the rapid growth of peacetime aviation, especially in the jet transport category, the risk of mid-air collisions and near misses has increased over the years. Although there have been improvements in control techniques and technology, all too frequently human error and lapses in control efficiency increase the probability of misses and collisions. From 1955 the development of airborne collision avoidance systems has been the subject of studies and research. In 1987 the United States - through the FAA - decided to introduce such a system on a large scale and the carriage of TCAS II equipment will become mandatory at the first of January 1994 for 100% (including Part 121 air carriers). TCAS II is a system that provides collision avoidance advisories, only in the vertical plane, by means of vertical speed commands. The TCAS interrogates transponder-equipped aircraft within its immediate vicinity. By measuring the time intervals between interrogation and reply, the TCAS computer can determine the relative range, bearing and altitude (the latter not possible for mode-A transponder-equipped aircraft). With this information the TCAS computer can determine a potential threat and will, if necessary, generate advisories.

Under a contract awarded by Fokker Aircraft B.V., NLR has conducted an evaluation study on its Research Flight Simulator in which the resolution advisory (RA) symbology is determined for implementation in the EFIS Primary Flight Display (PFD) format of the Fokker 100 aircraft [ref.13].

4.4 PHASE II FLIGHT SIMULATION MODEL CESSNA CITATION 500

Critical parts of flight crew training are carried out in ground-based flight simulators. Therefore the fidelity requirements of these flight simulators were tightened. For many aircraft, especially older types, the available flight test data and mathematical models are not adequate to serve simulators meeting the new high fidelity standard.

Through its involvement in several flight test programmes NLR has obtained expertise in dynamic flight test techniques tailored to extract maximum information on aircraft within a short period of flight test time. For accurate results NLR has developed high fidelity instrumentation systems, which are also capable of recording large data streams.

In order to cope effectively with the large data output use is made of computerized data processing. For the analysis and modelling efficient, user-friendly tools have been developed. Validation and evaluation of the simulation models, both off-line and on-line, can be performed on research flight simulators.

The National Aerospace Laboratory and Delft University of Technology have developed a Phase II Flight Simulation Model from flight test data collected during non-stationary manoeuvres for the Cessna Citation 500 of the Dutch Government Flying School.
4.5 ADVANCED FLIGHT CONTROL SYSTEMS (FBW)

In the area of Flight Control Systems, major developments have taken place during the last few years. Due to increasing automation, the introduction of so-called Glass-cockpit concepts and the changing opinion with respect to aircraft control, the need for criteria and guidelines for modern Flight Control Systems has been growing strongly.

The control of current generation aircraft uses mainly "attitude command" systems designed accordingly to criteria and rules published in MIL-spec's, SAE advisories, FAR/JAR certification requirements and reports of research carried out. These in principal military requirements are based upon results of international research executed with ground-based and in-flight simulators.

The military development with respect to concepts and criteria of new flight control systems is in advance of the civil development. Over the past years NLR increased its knowledge and experience with respect to handling-qualities design criteria by executing several flight simulator experiments [ref.14]. In 1987 an investigation was conducted on the NLR Research Flight Simulator, in relation with GARTEUR, into longitudinal handling qualities of advanced flight control systems for civil transport aircraft. Flight-path rate commanded systems, which might be used in the new generation of civil transport aircraft, were evaluated longitudinal as well as lateral [ref.15]. Due to the fact that the lateral flight control system was less advanced than the longitudinal system, in 1993 a new flight simulator experiment will be conducted with respect to design guidelines of new generation advanced lateral flight control systems for civil transport aircraft.

4.6 TAKE-OFF PERFORMANCE MONITOR SYSTEM (TOPMS)

Accident records indicate that take-off safety has not improved during the last two decades. Factors such as degraded engine performance, incorrect weight and tyre failures can adversely affect the take-off performance and often occur without crew recognition during everyday civil operations. Consequently the scheduled accelerate-stop distance may be exceeded even before the decision speed is reached and a decision made to reject take-off, or the later climb performance would be insufficient and unsafe.

Improvements in take-off monitoring would assist the pilot in detecting sub-standard performance and make it easier to decide if a take-off can safely be continued or to support the decision to abandon it. Take-off problems are reviewed and possible benefits of a Take-Off Performance Monitor System (TOPMS) examined [ref. 16]. In 1993 a simulation experiment will be conducted on the NLR Research Flight Simulator in which efficient systems will be evaluated.

4.7 CATEGORY III APPROACH AND LANDING

At present, it is common practice that under Category III visibility conditions an automatic approach is followed by an automatic flare and landing, requiring the aircraft to be equipped with an expensive autoland system.

To enable small and medium-size aircraft to perform landings under Category III visibility conditions, without the high cost of an autoland system, less expensive alternatives have been proposed, often called "economic Category III operations". Their application could extend the all-weather capability of smaller aircraft against affordable costs.

One of these proposals is an automatic approach followed by a manual flare and landing: certification of the autopilot system does not have to extend beyond the autopilot's Minimum Use Height and the autoland system is made superfluous. Fundamental to this concept, however is the feasibility of a manual flare and landing (or go-around) from below Decision Height, in which the visual references with the ground play an important role.

To study the feasibility of this concept, the National Aerospace Laboratory conducted an investigation into this type of procedure under contract to the Netherlands Department of Civil Aviation, RLD [ref. 17].

The prime objective of this investigation was the assessment of factors that play an important role in the pilot's decision when performing such type of approach under Category III visibility conditions. The second objective was to determine the feasibility of an automatic approach followed by a manual landing under Category III weather conditions. In order to meet these objectives, NLR's Research Flight Simulator was used to fly approaches under varying conditions. Major test design variables included Runway Visual Ranges between 150
and 250 metres, varying crosswind conditions and a fixed Decision Height of 50 ft. The autopilot Minimum Use Height was 40 ft.

The Research Flight Simulator was programmed with the handling qualities and characteristics of a medium-size jet transport aircraft, with final approach speeds representative for small and medium-size aircraft. The outside view was generated by a graphics workstation and the image displayed on the wide-angle collimating displays of the simulator cockpit.

For operations under low-RVR conditions it is essential to provide a correct runway lighting in order to provide the pilot with the proper visual cues. The graphics workstation offered this controllability and flexibility, especially with respect to the modelling of the runway markings and lighting as well as the visual sequences. Runway markings and lighting met the requirements for CAT III operations.

Three pilots, all experienced in CAT III operations, participated in this program, flying a total of almost one hundred approaches. During the approaches magnetic tape recordings were made and pilots had to fill in questionnaire forms.

4.8 MOVING AND FIXED THROTTLE LEVERS

In "conventional" aircraft with autothrust systems, the throttle levers move automatically when the systems initiate changes in thrust. The function of the throttle levers in the Airbus 320 however, is changed with respect to the conventional aircraft. The direct relation between variations in thrust and the actual position of the throttle levers is removed. The Airbus 320 throttle levers have the function of a thrust limiter and only indicate the maximum thrust available. The system is allowed to vary the thrust between idle and the thrust-limit set by the levers.

Because the throttle levers don't move, no information about the thrust-level is provided to the pilot from the levers. Airbus claims that the improved engine display will compensate for this loss of information.

It may be true that the fixed variant of the throttle levers could save costs in the production phase, but it could compromise flight safety. Therefore, a comparative study of both autothrust systems was commissioned by the Netherlands Agency for Aerospace Programs (NIVR) to the NLR [ref. 18].

Ten pilots flew both throttle-configurations in NLR's Research Flight Simulator. The variables used to describe the pilot performance, are: number of correct detections of problems and failures, detection time and thrust awareness. Questionnaires were used to measure the preference of the pilots for both autothrust systems.

Besides fixed throttle levers, other developments in modern aircraft have resulted in a reduction of available information about aircraft status. This also influences the awareness of the pilot. In all civil aircraft various sources provide complementary or similar information about the system. This is known as "redundancy of information" and stimulates mental awareness of aircraft status. In modern aircraft this redundancy slowly disappears. The sound of the engines is hardly observable and even the flow of the air-conditioning is stabilized. Pitch stabilization is generally accepted and level changes or altitude captures are not accompanied by clearly noticeable accelerations. This reduction in redundant information can lead to a decline of situational awareness.

4.9 WINDSHEAR

Strong windshears and downdrafts are still a considerable hazard to aviation. Therefore, the FAA has issued a requirement that all US-carriers install a first generation windshear detection system in aircraft with a capacity of more than 30 passengers, before January 1993. Although non US-carriers are not obliged to install those instruments yet, the emergence of next generation airborne windshear detection, alert and recovery systems may lead to improved, modified or even fully revised manually flown windshear recovery procedures. To keep pace with the impact of new system development on the existing manually flown procedures, it is necessary to direct research attention towards flight control aspects during windshear events [ref. 19].

In 1993 a simulator experiment is planned where the interaction between airborne and ground-based windshear detection systems will be studied.
4.10 OPERATIONAL AND HUMAN FACTOR ISSUES OF COCKPIT DATA LINK

Data link communication becomes ever more prominent in transport category aircraft. The digital exchange of information between aircraft and ground systems opens many opportunities and is expected to improve the quality and efficiency of the communication process. Voice communications can be supported by the transfer of accurate data and frequency congestions can be relieved. Company information is already distributed through a data link and can be used to improve efficiency and flexibility of operations. Further data link developments will not only alter the exchange of information between pilots and controllers, but also allow some integration of aircraft and ATC capabilities. This integration has the potential for increasing airspace capacity by more accurate navigation and trajectory prediction and is presently under investigation in many national and international research programs. It is therefore expected that the role of data link will rapidly gain importance and integration on the flight deck will occur for both existing and future aircraft.

The US Federal Aviation Administration (FAA) has adopted an active research strategy to develop minimum standards for data link integration on the flight decks of transport category aircraft. The research is performed in a joint effort of the FAA with European partners comprised by the Netherlands Department of Civil Aviation (RLD) and the National Aerospace Laboratory (NLR). Included in the scope of this research are procedural, operational and human factors issues as associated with electronic communication in all types of flight regimes and conditions. Of particular interest are operations in the oceanic environment where the potential exists for immediate savings in fuel and flight time. Flight operations for the studies planned will, however, include both European airspace and terminal area operations.

The fundamental changes in communication as introduced by data link raise many questions and issues that have to be resolved before safe and efficient introduction. Topics as display location, display function sharing and data link operability will guide the structure of the research for the first phase aimed at communication and crew performance issues.

In this simulation experiment both NLR’s Research Flight Simulator (RFS) and Air Traffic Control Research Simulator (NARSIM) will be used.

5 SIMULATION FACILITIES AT NLR

5.1 RESEARCH FLIGHT SIMULATOR (RFS)

The NLR Flight Simulation Group has at its disposal extensive facilities for different levels of simulation fidelity. From "simple" computer simulations on graphical workstations to full scenario man-in-the-loop moving base simulations (RFS).

The RFS, in operation since 1974, exists of a four degrees-of-freedom motion system (heave, roll, pitch and yaw), a television model board (scale 1:2000) visual image generator (terrain is 24.5 x 9.6 km, altitude max. 2000 ft), computer system, flight control desk, electronic interface system, an analog electro-hydraulic control loading system and different types of cockpits; single-seat fighter and side-by-side transport aircraft cockpit, both with a Wide-Angle Collimating Monitor Display system.

For the integrated design and evaluation of future air-traffic management systems, the RFS can be networked together with the NLR ATC research simulator (NARSIM) and the NLR research aircraft equipped as an Avionics Research Testbed (ART) [fig. 7].

An extensive package of software models is available to create, realistic atmospheric environment conditions, including microbursts, windshear and turbulence, functional navigation information, including ADF/VOR/DME, beacons, Instrument Landing System (ILS), Microwave Landing System (MLS) and latitude/longitude navigation. All simulation models are data file dependent for quick and highly-flexible simulation investigations. Extensive software graphical programs and libraries for simulation of Electronic Flight Instrument Systems (EFIS), aircraft accident/incident investigations and (visual) reconstruction are available.
5.2 NATIONAL SIMULATION FACILITY (NSF)

NLR has recently started the development of a flexible and versatile "National Simulation Facility" (NSF) as an extension to its existing flight simulation facilities. In its basic form, to be ready in 1994, the NSF will be equipped with a fully functional F-16 cockpit [fig. 8]. It will enable NLR to conduct research into pilot training, pilot workload and man/machine interfaces. The NSF will extend The Netherlands’ capabilities of participating in international co-development and co-production programmes. The NSF can be extended for simulating transport aircraft and helicopters as well.

The existing six degrees-of-freedom motion system, with high bandwidth and large excursions (e.g. heave 2.15 meters), will be used for the NSF. It was designed for high-fidelity simulation of fighter and transport aircraft and helicopters. It can be equipped with an F-16 cockpit or with other cockpits, depending on the aircraft type to be simulated. A powerful visual system will produce high-resolution computer-generated images. The equipment will be coupled to a multi-processor computer system by a high-performance digital interface network and controlled from its own modern flight control desk with monitors and touch screens. For the simulation of sustained G-forces a g-seat will be installed in the cockpit.

Funding of the National Simulation Facility was approved by CODEMA, the Netherlands Commission for Development of Defence Materiel. CODEMA’s approval followed discussions on the need for an advanced research simulation facility in The Netherlands held by representatives of the Ministry of Defence and the Ministry of Economic affairs with representatives of research institutes and of industries. A need was felt for a high-performance, versatile simulation facility to be used in research supporting both the armed forces and the industry.

The new facility will be used to serve industry in the development and evaluation of new systems, for studying the effectiveness of simulation in training and education, for training of special circumstances in realistically simulated environments and for testing operations.

The NSF will be capable of performing these tasks by full scenario simulation. It will feature high-quality vehicle handling and have a high-performance motion system and a powerful visual system. Both hardware and software will have interchangeable modules, to make the NSF flexible and versatile.

NLR will operate the NSF under contract to a variety of civil and military customers, both from The Netherlands and from abroad. The basic facility will be capable of supporting research into fighter aircraft and fighter operations. It can be extended to enable research to be carried out on transport aircraft, tactical helicopters and transport helicopters, and even on land vehicles and fast ships.

6 CONCLUDING REMARKS

The safety of future air transportation systems will increasingly depend on the quality of the human interface and the quality of the pilots operating them. Research simulators can provide a vital means of evaluating transportation systems in conjunction with the limitations of the humans operating them. Furthermore, research simulators can be used to investigate the fundamentals of simulation-related technologies such as mathematical modelling, and motion control technologies. These topics will ensure that future flight simulator training systems provide pilots with cues which optimally match the characteristics of the actual aircraft.

Together, the Delft University of Technology, and the National Aerospace Laboratory will improve simulation technology, and use their research simulation facilities to optimize the future cockpit environment.

7 REFERENCES


2. Baarspul, M., "The Generation of Motion Cues on a Six-Degrees-of-Freedom Motion System". Delft


Figure 1
Existing three-degrees-of-freedom flight research simulator

Figure 2
Basic Research Simulator "Baresim" (artist’s impression)

Figure 3
Four-dimensional navigation "tunnel-in-the-sky" display
Figure 4
Basic Research Simulator cross-section shown in helicopter configuration

Figure 5
Two-seat transport aircraft research station, showing glass cockpit and controls (yokes or sidesticks available)
Figure 6. Microwave Landing System (MLS) coverage area

Avionics Research Testbed (ART)

ATC Research Simulator (NARSIM)  Research Flight Simulator (RFS)

Figure 7. NLR "networked" simulation research facilities
ACCIDENT DATA
INLAND WATERWAY TRANSPORT: MODELLING THE PROBABILITY OF ACCIDENTS

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Abstract

In 1989 the Dutch government started the project "Safety in Inland Waterway Transport" to establish a minimum safety level and to develop a model to assess the effect and effectiveness of new safety measures. This model is called the Risk Effect Model, and it is to calculate the integral impacts of safety measures for the entire waterway system including the risks of transporting dangerous goods. The final result of the project is a framework for evaluation, that supports cost-benefit analysis by weighing negative economical effects against achievements in safety, for different measures.

In this paper we will present the methods which have been used to calculate the probability of an accident, using casuistry. In this project the probability of an accident is modelled per elementary traffic situation (a combination of several ships carrying out a ship motion produces a traffic situation). The number of accidents can be estimated by the number of elementary traffic situations multiplied by the probability of an accident per elementary traffic situation.

In the paper we describe fitting procedures in order to obtain the model that "forecasts" the probability of accidents as function of waterway attributes and circumstances. We have used Generalized Linear Models (GLM), which do not need the assumption that the accident probability is normally distributed. We have used the binomial approach in the GLM models.

We present the results of the fitting procedures for one group of elementary traffic situations (through-going traffic mutually). The primarily governing variables appear to be visibility, wind speed, the ratio of the navigable width and the necessary width for an elementary traffic situation, and the bend radius of the waterway. The circumstances (visibility and wind speed) are more explanatory with respect to the probability of accidents than the waterway characteristics are.
1. Introduction

Inland waterway transport in the Netherlands has been and will be very important. About 250 million tonnes of cargo are shipped over inland waterways (Bos et al., 1991). The market share of the international cargo transport via waterways to and from the Netherlands expressed in tonnes is roughly 50%. The most important connections are between Amsterdam, Rotterdam and Antwerp via the Rhine to Germany. About 3350 kilometers of navigable inland waterway are available for cargo transportation. Lay-out and control of the waterway network is an important yet costly job, deploying many people. Waterway management constantly strives to improve the methods of design and control.

An important subject in view of the safety of vessel traffic is risk analysis. In the Netherlands the safety of transporting dangerous goods has become a point of increasing concern. One of the main topics in risk analysis is the transport of dangerous goods. If a vessel loaded with dangerous goods becomes involved in an accident that results in the release of those materials (e.g. toxic gas), people who live near the waterway might become victims. The number of deaths can be fairly high (10 - 100). Fortunately the probability of such an accident occurring is very low (10⁻⁹ per vessel kilometer) (Bos et al., 1991).

Because of the possible consequences of an accident for the Dutch population and in view of an expected increase in waterway transport, the government attaches great importance to safety in inland waterways. It is therefore desirable to investigate the probability of such accidents occurring and the number of possible victims. These investigations would be carried out as a combination of accident analysis and effect analysis. The accident analysis results in the probability of accidental release of a certain quantity of dangerous goods. The effect analysis results in the chance of people living along the waterway being killed as a consequence of the release of dangerous goods.

Since 1977 the Netherlands have a nationwide, uniform system for registration of vessel traffic accidents. This greatly facilitates accident and risk analysis. The central database is managed by the Ministry of Transport and Public Works (Rijkswaterstaat, Dienst Verkeerskunde). The information covers details such as date, location, weather conditions, ship dimensions, loading capacity, technical defects, VHF communication, casualties, damages to vessels and fairway, environmental damage, etc.

In 1989 the Dutch government started the project 'Safety in Inland Waterway Transport' in order to quantify the risks, to establish a minimum safety level and to develop a model to calculate the effectiveness and possible side effects of new safety measures. This model is called the Risk Effect Model. This model is not restricted to the transport of dangerous goods. The integral effect of safety measures for the entire inland waterway transport has to be estimated.

This Risk Effect Model shall enable calculation of the effect of measures with respect to multiple criteria, like safety of people living along waterways, economics and environment. The effect of measures must be made visible by changing the input for one or more submodels. The structure of the model is discussed in (De Vries et al., 1992) and roughly outlined in figure 1.1.

This paper only deals with methods for determining the probability of the occurrence of an accident, irrespective of the extent of damage (the probab model in figure 1.1). The paper is further restricted to a casuistic approach. Other methods as employed within the safety of water transport project are not treated here.
2. The casuistic approach of the probability of accident model

The base for calculation of risks is in general:
- identification of the risks
- determination of the exposure to risk
- estimation of the risk per exposure

Several accident types were identified. It was assumed then, that a ship’s exposure to risk (or rather to the possibility of an accident) is related to a certain traffic situation. Several traffic situations were identified, related to the accident types. We call these the elementary traffic situations (ETS). The types of accidents and related ETS types are called groups. So far, five groups are distinguished.

The exposure in group 4 and 5 is related to vessel kilometers and the quayage (total length of quay in a waterway section). When there is more quayage more ships are able to berth and more manoeuvring situations may be expected. A true number of manoeuvres etc. could not be determined.

The probability of an accident while an ETS occurs, is assumed to depend on:
- the lay-out and other characteristics of the waterway,
- the circumstances (like visibility and wind),
- the kind of ETS, and
- the type of ships involved in the ETS.

The model must give the relation between the probability of an accident and these four influence factors. However, in this paper the relation between the type of ship and the probability of an accident is not discussed. It is not possible to find a correlated influence of lay-out, circumstances and type of ship, because of an insufficient amount of data.
Table 2.1 Groups of accidents and related exposure

<table>
<thead>
<tr>
<th>nr.</th>
<th>type of accident</th>
<th>exposure parameter</th>
<th>name of group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>collision when meeting or overtaking</td>
<td>meeting, overtaking encounters or combination (2 or 3 ships)</td>
<td>going-through mutually</td>
</tr>
<tr>
<td>2</td>
<td>collision between going-through and crossing ships</td>
<td>crossing encounters at junctions and crossings (2 ships)</td>
<td>going through- crossing</td>
</tr>
<tr>
<td>3</td>
<td>collision between crossing ships</td>
<td>same</td>
<td>crossing -crossing</td>
</tr>
<tr>
<td>4</td>
<td>collision between going-through and moored, anchored or manoeuvring</td>
<td>ship-kilometer (1 ship) and quay-length</td>
<td>going-through- moored/ anchored / manoeuvring</td>
</tr>
<tr>
<td>5</td>
<td>collision between moored, anchored, manoeuvring ships mutually</td>
<td>quay-length</td>
<td>moored/ anchored/ manoeuvring mutually</td>
</tr>
</tbody>
</table>

The relations were quantified by linear functions, for reasons of simplicity. More sophisticated model structures will be investigated when results indicate this as necessary. In order to estimate the number of accidents we need to know the number of ETS. This number of ETS is calculated with a Traffic Model, based on the number of ships entering or leaving a certain part of the waterway.

An outline of the data flow in the Probability-of-Accident-model is given in figure 2.1.

![Figure 2.1 Outline of the data flow in the sub-model "Probability of an accident"](image-url)

Figure 2.1 Outline of the data flow in the sub-model "Probability of an accident"
3. Estimators and Generalized Linear Models

3.1 Estimators
In this paragraph an estimator for the probability of an accident, given an ETS is derived. We will not treat problems caused by an insufficient amount of data. Bayesian Updating techniques to handle this problem are discussed in (Roelven, 1992).

When an ETS takes place, there are two possibilities:
- an accident occurs,
- no accident occurs.

Many such "experiments" take place. This suggest modelling this process like a Bernoulli-experiment, where we (cynically) call an accident a "success". 

Now, let \( z \) be the number of successes in a sample of \( n \) such experiments and \( p \) the probability of success, then \( z \) is binomially distributed according to:

\[
f(z; p) = \binom{n}{z} p^z (1-p)^{n-z}
\]  

(3.1.1)

3.2 Generalized Linear Models
For Least Square Estimation it is necessary to assume that the observations, or data points, contain a statistical fluctuation which has a normal distribution. The theory of Least Square estimation can be generalized to data points with a statistical fluctuation with an arbitrary distribution. This extension of the theory of LSE is called Generalized Linear Models (GLM). This theory is suitable for distributions from the exponential family, like the binomial distribution.

The estimation procedure starts with selection of an a priori model. Secondly, a measure of goodness of fit between the observed data and the fitted values generated by the model must be defined. Thirdly, the parameters must be estimated and the precision of the estimates must be determined. The parameter estimates are the values that minimize the goodness-of-fit criterion. We follow the maximum likelihood or log likelihood method, as described by McCullagh and Nelder (1989):

Suppose we want to estimate the probability \( p \), based on an observation \( z \) of the random variable \( Z \), then the likelihood of the estimator \( \pi \) for \( p \), given the particular observation \( z \) is defined as:

\[
L(\pi; z) = f(z; p=\pi)
\]  

(3.2.1)

Here \( f(z; p) \) is the density- (or probability-) distribution of \( z \), given the probability \( p \).

In words: The likelihood of the estimate \( \pi \) equals the probability of the observation \( z \), assuming that the estimate is correct.

The log likelihood is defined as:

\[
\ell(\pi; z) = \log f(z; \pi)
\]  

(3.2.2)

The log likelihood based on a set of independent observations \( z_1, \ldots, z_N \) of \( Z_1, \ldots, Z_N \) is the sum of the individual contributions, so that

\[
\ell(\pi_1, \ldots, \pi_N; z_1, \ldots, z_N) = \sum_{i=1}^{N} \log f(z_i; \pi_i)
\]  

(3.2.3)
Note that the log likelihood is considered as a function of \( \pi \) for the particular data \( z \), whereas the density function \( f(z;p) \) is considered as a function of \( z \) for fixed \( p \).

There are advantages in using as goodness-of-fit criterion the **scaled deviance**, defined as follows:

\[
D(\pi_1, \ldots, \pi_N; z_1, \ldots, z_n) = 2U(z_1, \ldots, z_n; z_1, \ldots, z_n) - 2U(\pi_1, \ldots, \pi_N; z_1, \ldots, z_n)
\]  

(3.2.4)

Note that for exponential-family distributions the first term in (3.2.4) is the maximum likelihood achievable for an exact fit. Because this term does not depend on the parameters, maximizing the log likelihood is equivalent to minimizing the scaled deviance, with respect to \( \pi_i, i = 1, \ldots, N \), subject to the constraints imposed by the model.

When \( f \) is the binomial distribution (with \( n \) observations, probability of success \( p \) and the number of successes \( z \)):

\[
f(z; n) = \binom{n}{z} \pi^z (1 - \pi)^{n-z}
\]  

(3.2.5)

the deviance function is:

\[
D(\pi; z) = 2z \log \left( \frac{z/n}{\pi} \right) + 2(n-z) \log \left( \frac{1-z/n}{1-\pi} \right)
\]  

(3.2.6)

**Link Function**

An essential and necessary element of the GLM approach is the **link function**. The link function relates a linear predictor \( \eta \) to the expected value of an estimator \( \pi \). Since \( \pi \) denotes a probability, we have 0 < \( \pi \) < 1 and a link function should satisfy the condition that it maps the interval (0,1) on to the real line. The **logit** link function seems to be most suitable:

\[
\eta = \log \left( \frac{\pi}{1-\pi} \right)
\]  

(3.2.7)

**Application for Accident Probability Model**

Suppose we have the following accident data for \( N \) states:

\( z_i \) : number of accidents observed in state \( i \),

\( n_i \) : number of ETS taken place in state \( i \),

\( S_i \) : vector of descriptive variables of state \( i \),

\( \alpha \) : vector of parameters \( \alpha_1, \alpha_2, \ldots, \alpha_M \) of the model,

\( M \) : the dimension of \( S \) and \( \alpha \) is the number of parameters in the model.

The relation \( \pi(S) \) between the probability of an accident and the description of the state can be found by:

\[
\min_{\alpha} \sum_{i=1}^{N} z_i \log \left( \frac{z_i/n_i}{\pi(S_i)} \right) + (n_i - z_i) \log \left( \frac{1-z_i/n_i}{1-\pi(S_i)} \right)
\]

subject to \( \pi(S) = \frac{e^{\alpha^TS}}{1+e^{\alpha^TS}} \)  

(3.2.8)
4. Data

4.1 Waterway characteristics
Table 4.1 lists the data which is used to characterize waterways.

<table>
<thead>
<tr>
<th>waterway characteristic</th>
<th>dimension</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>start of section</td>
<td>km.</td>
<td></td>
</tr>
<tr>
<td>end of section</td>
<td>km.</td>
<td></td>
</tr>
<tr>
<td>through-going</td>
<td>0/1</td>
<td></td>
</tr>
<tr>
<td>junction</td>
<td>0/1</td>
<td></td>
</tr>
<tr>
<td>crossing</td>
<td>0/1</td>
<td></td>
</tr>
<tr>
<td>presence of lock</td>
<td>0/1</td>
<td></td>
</tr>
<tr>
<td>presence of weir</td>
<td>0/1</td>
<td></td>
</tr>
<tr>
<td>presence of bridge</td>
<td>0/1</td>
<td></td>
</tr>
<tr>
<td>length of section</td>
<td>m.</td>
<td></td>
</tr>
<tr>
<td>length of quay</td>
<td>m.</td>
<td>- quayage</td>
</tr>
<tr>
<td>navigable width</td>
<td>m.</td>
<td>- navigable width of waterway</td>
</tr>
<tr>
<td>bend radius</td>
<td>m.</td>
<td></td>
</tr>
<tr>
<td>angle of deflection</td>
<td>degrees</td>
<td></td>
</tr>
<tr>
<td>crossing angle</td>
<td>degrees</td>
<td>- angle between the two waterways</td>
</tr>
<tr>
<td>crossing overview</td>
<td>m.</td>
<td>- distance of view to see traffic</td>
</tr>
<tr>
<td>visibility station</td>
<td>station</td>
<td>most representative meteorological stations</td>
</tr>
<tr>
<td>wind station</td>
<td>station</td>
<td></td>
</tr>
<tr>
<td>flow regime</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Two more (mathematical) characteristics are introduced:
- width-ratio: this is the average width needed for the elementary traffic situations, divided by the navigable width. The width-ratio is output of the Traffic Model (like the number of ETS), and is defined only for the ETS of group 1.
- relative quayage: the ratio of length of quay and length of section

4.2 Circumstances
The following three circumstance-variables were considered:
- visibility (in km.): maximal distance of sight over the waterway
- wind speed (in m/s.)
- current velocity (in m/s.)
The visibility and windspeed are divided into 3 classes, the current velocity into 4 classes. This makes 36 circumstances-classes.
In total, the information of fourteen meteorological stations of the Royal Dutch Meteorological Institute was used to determine the relative frequency of occurrence for the variables visibility and wind speed. River flow statistics and tidal flow atlases were used for the current velocity.
5. Results

5.1 Global Analysis of Accidents and Elementary Traffic Situations

Twelve major waterways were selected for analysis in the project. Accidents involving small pleasure craft only, were discarded. Between 1 January 1978 and 31 December 1988 approximately 5200 accidents within this selection have been registered at Rijkswaterstaat. The accidents were allocated to one of the five groups as defined in table 2.1. The number of accidents per group is presented in table 5.1 for each waterway.

Table 5.1 Number of accidents for each group for the twelve major waterways registered between 1978 and 1988 (11 years).

<table>
<thead>
<tr>
<th>Name of Waterway</th>
<th>number of accidents</th>
<th>number of accidents</th>
<th>number of accidents</th>
<th>number of accidents</th>
<th>number of accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>group 1</td>
<td>group 2</td>
<td>group 3</td>
<td>group 4</td>
<td>group 5</td>
</tr>
<tr>
<td>1. Waal</td>
<td>445</td>
<td>38</td>
<td>21</td>
<td>553</td>
<td>514</td>
</tr>
<tr>
<td>2. Amsterdam-Rijnkanaal</td>
<td>126</td>
<td>8</td>
<td>5</td>
<td>209</td>
<td>127</td>
</tr>
<tr>
<td>3. Pr. Margrietkanaal</td>
<td>90</td>
<td>12</td>
<td>21</td>
<td>112</td>
<td>143</td>
</tr>
<tr>
<td>4. IJssel</td>
<td>59</td>
<td>4</td>
<td>2</td>
<td>140</td>
<td>151</td>
</tr>
<tr>
<td>5. IJsselmeer</td>
<td>12</td>
<td>2</td>
<td>10</td>
<td>32</td>
<td>141</td>
</tr>
<tr>
<td>6. Noordzeckanaal</td>
<td>14</td>
<td>1</td>
<td>5</td>
<td>40</td>
<td>142</td>
</tr>
<tr>
<td>7. Nieuwe Maas</td>
<td>69</td>
<td>48</td>
<td>35</td>
<td>115</td>
<td>243</td>
</tr>
<tr>
<td>8. Schiphol-R'dam</td>
<td>36</td>
<td>7</td>
<td>13</td>
<td>67</td>
<td>99</td>
</tr>
<tr>
<td>9. Schelde-Rijn</td>
<td>86</td>
<td>10</td>
<td>18</td>
<td>238</td>
<td>137</td>
</tr>
<tr>
<td>10. Maasroute</td>
<td>68</td>
<td>16</td>
<td>8</td>
<td>38</td>
<td>115</td>
</tr>
<tr>
<td>11. Westerschelde</td>
<td>48</td>
<td>10</td>
<td>18</td>
<td>185</td>
<td>118</td>
</tr>
<tr>
<td>12. Dordtse Kil</td>
<td>16</td>
<td>5</td>
<td>1</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>1015</td>
<td>161</td>
<td>157</td>
<td>1772</td>
<td>1944</td>
</tr>
</tbody>
</table>

Most of the accidents take place in group 4 (going-through- moored/ anchored / manoeuvring) and group 5 (moored/ anchored / manoeuvring mutually). The damage in these groups is mostly slight, because the velocity of the ships is low when they are manoeuvring.

With the output of the Traffic Model aggregated over the sections of the waterways, a probability of accidents per waterway and the "average nation wide" Accident Probability is estimated. These estimates are displayed in table 5.2.

Remark: In this table only vessel kilometers were used as exposure for groups 4 and 5.

Table 5.2 Estimators for average nation wide Accident Probability

<table>
<thead>
<tr>
<th>Group</th>
<th>Accident Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.7 \times 10^{-6} per ETS</td>
</tr>
<tr>
<td>2</td>
<td>1.5 \times 10^{-6} per ETS</td>
</tr>
<tr>
<td>3</td>
<td>2.9 \times 10^{-6} per ETS</td>
</tr>
<tr>
<td>4</td>
<td>6.1 \times 10^{-6} per vessel km</td>
</tr>
<tr>
<td>5</td>
<td>6.7 \times 10^{-6} per vessel km</td>
</tr>
</tbody>
</table>

Groups 2 and 3 appear to be more accident sensitive than group 1. Elementary traffic situations on crossings and junctions involving crossing movements are more dangerous (as could be expected). However, these groups do not have a major contribution to the number of accidents. Safety
measures with respect to traffic situations on junctions will not produce a great decrease in the number of accidents.

5.2 Results of Generalized Linear Models
An extensive description of the fitting procedure can be found in (Lans, 1992). Here we only present the results for group 1. We started with the null model (a constant probability according to table 5.2). Then in a number of expansions the variable that caused the greatest reduction of the deviance was added to the model. After five expansions, introducing another variable (or cross-term) did not reduce the deviance significantly. The resulting model reads as follows:

\[ \eta(Y,X) = \frac{e^{\eta(Y,X)}}{1 + e^{\eta(Y,X)}} ; \]

\[ \eta(Y,X) = -10.1 + 7.1Y_1 + 370Y_2 - 1.5X_1 - 0.38X_2 + 0.16X_1X_2 \]

with \( Y_1 = \text{width-ratio} \)
\( Y_2 = (\text{bend radius})^{-1} \)
\( X_1 = \text{visibility} \)
\( X_2 = \text{wind speed} \)

The deviance of this model is 256; a reduction of 978 relative to the null model.

The explanatory value of each variable can be indicated by the reduction of the deviance. The reduction of the deviance caused by introducing the variable in the model is presented in table 5.3.

It appears that the circumstances-variables are more explanatory than the situation-variables.

### Table 5.3
Reduction of deviance when the variable is introduced in the model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Comments</th>
<th>Reduction of Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_1 )</td>
<td>Visibility</td>
<td>506.39</td>
</tr>
<tr>
<td>( Y_1 )</td>
<td>Width-ratio</td>
<td>324.97</td>
</tr>
<tr>
<td>( X_2 )</td>
<td>Wind speed</td>
<td>79.73</td>
</tr>
<tr>
<td>( X_1 \ast X_2 )</td>
<td>cross-term</td>
<td>48.98</td>
</tr>
<tr>
<td>( Y_2 )</td>
<td>((\text{bend radius})^{-1})</td>
<td>17.54</td>
</tr>
</tbody>
</table>

Note that no cross-terms between circumstances and waterway characteristics appear in the model.

The influences of the two circumstances-variables and the two waterway characteristics seem to be uncorrelated.

5.3 Comparison of predicted and observed accident counts

The question now arises, if there is enough resemblance between the model predictions and the data. Comparison leads to the conclusion, that there are several fairway sections that show a completely different number of accidents than expected according to the model. Amongst these are the known accident concentration spots. The accident risks in these spots are determined in most cases by a complex of factors. As yet, simple models as shown above are not able to describe such situations. Excluding such situations, however, the model gives a fairly good description of the influence of fairway width and bend radius on the accident probability. Figures 5.1 and 5.2 show the comparison of actual and predicted numbers of accidents in sections of the river Waal and Amsterdam Rijnkanaal respectively.
Figure 5.1  Predicted versus observed number of accidents for meeting ships (group 1) on river Waal

Figure 5.2  Predicted versus observed number of accidents for meeting ships (group 1) on Amsterdam Rijnkanaal
6. Conclusions

The Accident Probability is modelled per Elementary Traffic Situation (ETS). The state is described by the lay-out of the waterway and the circumstances. This way of modelling seems to be useful.

The governing variables in the model for through-going traffic appear to be visibility, wind speed, the ratio of the navigable width and the necessary width for an ETS and the bend radius of the waterway. The circumstances (visibility and wind speed) are more explanatory than the waterway characteristics are. This could imply that safety measures with respect to circumstances would have more impact than changing the waterway characteristics. However, this conclusion can not be drawn until the characteristics used to describe the lay-out of the waterway have been expanded.

From the investigated data set it appears that the influence of circumstances and waterway characteristics is not correlated. For example, the influence of poor visibility on accident probability in a narrow waterway is equal to the influence of poor visibility in a wide waterway.

In the final model only four variables remain. It is obvious that this model doesn’t enable determining the effect of many safety measures. Further Analysis on the data is carried out in order to reveal more information. However, other sources of information, for example expert opinions, see (Cooke, 1991) can be used as well.

References

"Modern Methods for the design and control of inland waterways", 27th International Navigation Congress, PIANC, OSAKA, may 1990

Cooke, R.M. (1991)


"Veiligheid Vervoer over Water; Inventarisatie ongevalsscenario’s en opzet kwalitatief risico/effect model", Delft Hydraulics project h1/h2, november 1990.

ACCIDENT PREDICTION MODELS FOR SIGNALIZED CROSSWALKS

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Abstract
In Poland, there is an obvious need for effective countermeasures to elevate traffic safety, especially pedestrians safety. The paper present results of study of pedestrian safety on signalized crosswalks. A regression technique was used in the investigation of factors-accidents relationships and, then, the accident predictive models have been developed.

The models have been used to highlight and quantified the effects of traffic and signals impacts on the pedestrian safety. The study has shown that short-term measurements carried on specially for a purpose of a safety analysis or those conducted by traffic authorities on a regular basis provide sufficient data base for developing accident regression models. The method of accident prediction applicable in non-stationary conditions, as these faced in Poland and other East European countries, has been proposed in the paper.

1. Introduction

Pedestrians are road users much more exposed than others on injury or death in a traffic accident. In Poland the ratio of pedestrian accidents-to-injury accidents (around 45%) are higher than in other European countries. In urban areas this ratio is even higher and approaches the value of 60%. Each third pedestrian involved in a traffic accident is run over at a marked crosswalk. It is surprising that high pedestrian accident risk persists also at crosswalks controlled with traffic signals. Unfortunately, in Poland the recent 2-3 years of the economical and political transition have brought substantial deterioration of traffic safety [1]. Thus, there is an obvious need for some effective countermeasures to elevate traffic safety on Polish roads, especially pedestrians safety.
Accident trends, especially alarming situation in pedestrian safety, encouraged the authors to undertake the problem of pedestrian accident risk at signalized crossings in order to:
- identify pedestrian accident factors,
- develop accident prediction models,
- assess the efficiency of accident countermeasures and pedestrian facilities in Poland.

In this paper the one phase of the study is presented, including the development of prediction models of pedestrian accident frequency at signalized crosswalks and the approach to accident analysis when instability of accident frequency can not be neglected in an accident prediction.

2. Data base

The accident models application for cost analysis of alternative solutions and for management schemes evaluation requires model inputs available in a designing or evaluation stage. Moreover, in 'black pots' selection, the large number of sites in a traffic network needs to be considered, thus, required data should be easy and inexpensive to collect. In our study, the following data set has been collected for each pedestrian crossing:
- number of pedestrian accidents in each year of the period 1984-90,
- vehicle and pedestrian volumes, Q and P respectively,
- total volume N of buses and trams at all stops located near a given crossing,
- percent u of vehicles lawfully passing a crosswalk in a pedestrian phase (turning movements at a two-phase signal or/and on a green arrow),
- roadway width,
- distance between a crosswalk axis and a vehicle stop-line,
- required walking speed $v_p$ which prevents pedestrians from being trapped in a pedestrian refuge area by a signal change to red; $v_p = \frac{L}{G}$, where $G$ is a pedestrian green and $L$ is the sum of a refuge area width and a roadway width. Pedestrians are assumed to step onto a roadway at the beginning of green signal. The speed $v=0$ if a given street has one roadway,
- number of vehicle traffic lanes on a roadway where a given crosswalk is marked,
- number of directions from which conflicting vehicles are expected by a pedestrian,
- central reserve or refuge island for pedestrians $\delta$ (1 if refuge area occurs, 0 if not),
- tram stop adjacent to a roadway with a given crosswalk,
- function of a surrounding area,
- speed limit,
- signal cycle,
- length of a vehicle phase which is the sum of vehicle green period and vehicle clearance time,
- vehicle phase-to-cycle ratio $\rho$,
- pedestrian and vehicle clearance times.
Daily traffic volumes are usually used in accident frequency modeling. Because of incompleteness of traffic volumes files collected by traffic authorities, own traffic counts were required. Using historical data, an optimal time of day of two half-hour traffic counts has been selected in such way, that the short-term counts give the smallest error of daily traffic volume estimation. The regression models of 24-hour pedestrian and vehicle traffic volumes have been developed. Then, the field short-term traffic counts of vehicles and pedestrians were carried out two times at each of 75 crosswalks to provide sufficient data base for 24-hour volumes estimation at the investigated crosswalks. An additional analysis allowed to conclude that also the 3-hour counts, conducted in Poland on regular basis to select peak-hour traffic volumes, are useful in an accident analysis.

Other remaining data on accident, geometry and traffic have been taken from data files available from appropriate institutions and authorities.

3. Methodology

A regression technique is widely used and accepted in an investigation of factors-accidents relationships for its capability to include in accident predictive models an exposure to accidents together with other road and traffic factors. Analysis of single road facilities (road sections, intersections) are especially difficult due to a low frequency of accidents and accident distribution other than Normal. The generalized linear regression [2] allows to overcome these difficulties. The Poisson or Binomial negative distributions are usually assumed in accident frequency modeling [3,4]. In the presented study the Poisson distribution has been assumed together with the following general regression model form:

\[ A = k \cdot Q^a \cdot P^b \cdot \exp(\Sigma a_i x_i) + c \]  

(1)

where:
- \( A \) = accident frequency (accidents/time period),
- \( Q \) = weekday vehicle volume (veh/24h),
- \( P \) = weekday pedestrian volume (ped/24h),
- \( x_i \) = factor \( i \) included in the model (explanatory variable),
- \( k, a, b, a_i \) = regression parameters,
- \( c \) = random component which follows the Poisson distribution.

A significance tests are based on a scaled deviance \( D \) - a likelihood measure of a discrepancy between two models [2]. The scaled deviance between a given model and a null model (sample mean) is used in testing significance of a whole model, while significance of each factor is based on the decrease of the scaled deviance \( D \) after an inclusion of a considered factor into the model. The \( \chi^2 \) distribution has been assumed in the analysis. This assumption seems to be valid because of the average number of accident in the sample.
higher than 0.5. The Mean Deviance Ratio (MDR) is an auxiliary statistic used in the significance testing. MDR is calculated as follows:

\[
\text{MDR} = \frac{\text{Scaled deviance difference/D.o.f. difference}}{\text{Residual scaled deviance/D.o.f. of the best model}}
\]

The scaled deviance and degree of freedom differences refer to two considered models while the residual scaled deviance is a scaled deviance of the best fitting model. The MDR is approximately distributed as the F statistic.

A step-wise regression analysis [5] has been applied to select all factors significant at the 10% level of significance from these set up in Section 2. In the model extension two explanatory variable types have been considered. A simple quantitative variable \( X \) is represented in the model by the expression \( \alpha_1 \cdot x \), where \( \alpha_1 \) is a regression parameter, while the second hierarchic variable is expressed by \( \delta \cdot X \), where \( \delta \) is the qualitative variable with \( n \) levels and \( X \) is a simple quantitative variable. The variable \( \delta \cdot X \) is represented in the model by the expression \( \alpha_1 \cdot x \), where \( \alpha_1 \) corresponds to the level 1 of the variable \( \delta \).

4. Discussion of results

The regression procedure described in the previous Section has given the following prediction model:

\[
w = 0.0120 \cdot Q \cdot p^{0.2} \cdot e^{0.9 \cdot N + 2.3 \cdot (p - 0.5)} + 3.5 \cdot \delta \cdot u
\]

where:

\( w \) = accident frequency (accidents/year),
\( Q \) = vehicle volume (veh/24h),
\( P \) = pedestrian volume (ped/24h),
\( N \) = public transport vehicle volume (veh/24h),
\( p \) = vehicle phase-to-cycle ratio (-),
\( \delta = 1 \) if a pedestrian refuge area occurs, 0 otherwise,
\( u \) = proportion of vehicles passing a given crosswalk when green signal is displayed for pedestrians.

The regression parameters and other statistics are set up in Table 1. Figure 1 depicts the comparison of the predicted mean pedestrian frequencies to the observed frequencies over the 5-year period 1984-88. The pedestrian volume in the above model usually needs additional traffic counts, because this data are rarely collected in regular measurements. To avoid this difficulty, the additional model has been developed from which the pedestrian volume factor is excluded:

\[
w = 0.0169 \cdot Q \cdot e^{1.1 \cdot N + 2 \cdot (p - 0.5)} + 3.5 \cdot \delta \cdot u
\]

where notations are explained in Equation 3.
The regression analysis results for the model (3)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Regr. param.</th>
<th>Std. err. of par. estim.</th>
<th>Sc. dev. D/l.o.f.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope parameter $\ln(k)$</td>
<td>-3.93</td>
<td>0.84</td>
<td>196.9/74</td>
</tr>
<tr>
<td>Vehicle volume $Q$ (thus. veh/24h)</td>
<td>1.00</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>Pedestrian volume $N$ (thus. ped/24h)</td>
<td>0.18</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Public transport vehicle volume $Q$ (thus. veh/24h)</td>
<td>1.93</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>Vehicle phase-to-cycle ratio $\rho$ (-)</td>
<td>2.29</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td>Portion of vehicles passing crosswalk in vehicle phase $\delta_u$ (-)</td>
<td>3.46</td>
<td>0.71</td>
<td>71.1/69</td>
</tr>
</tbody>
</table>

Fig. 1 The comparison of the predicted pedestrian accident frequencies to observed values.
The scaled deviance D - a measure of model effectiveness is in the second model only slightly higher than in the first model. Also the regression parameters have values similar to those in the previous model.

In Poland the bus or tram stops are usually a strong pedestrian traffic generator. Thus, it is not surprise that significant correlation has been found between pedestrian volumes on crosswalks and public transport vehicle volumes at the stops functionally connected with these crosswalks. In consequence, bus and tram volumes can partially substitute pedestrian volume in the model as an explanatory variable. It is a likely explanation, why an effectiveness of both models is similar. The question is, however, whether the model (4) can be used in whole range of traffic volumes. The comparison of the accidents frequencies given in both models allows to ascertain similar results for a broad range of traffic volumes. The model (4) can be used when a value of pedestrian volume on a crossing remains between 4 000 and 16 000 ped/24h, particularly, when vehicle volume is moderate or low (below 14 000 veh/24h). The formula (4) should not be used if the pedestrian volume is very low, let say, less than 2 000 ped/24h. In that case, the formula (3) and, at least, rough pedestrian volume estimation are recommended.

The vehicle ratio \( u \) has been found an important pedestrian accident factor at the crosswalks with a pedestrian refuge area (usually intersection approach with channelization). The ratio \( u \) is not directly available in an analysis but it can be assessed analytically from vehicle movement volumes with some simplifying assumptions about turning movements performance at a signalized intersection.

From the traffic engineering standpoint signal timings can be considered as one of the most important accident factors. A signal program is the 'softest' element in an intersection designing. It does not need an additional investment and is easy to change also at existing intersections. The effect of signal setting at the simple one-way streets crossing is presented in Figure 2. Although the red-to-green ratio \( p \) can change the accident frequency over twice, this benefit is easy to gain only at a single pedestrian crossing. When taking into account an intersection with conflicting streams, total benefit is less and can reach 50% accident reduction when comparing the worse and best signal timings. It is worthy to notice, however, that optimal signal timings maximizing pedestrian safety gives contrary signal lengths to these which minimize total vehicle delay at an intersection. Figure 2 shows also the effect of bus and tram stops located near the intersection.

A phase sequence is the next issue in signal settings designing. The results suggest the negative effect of vehicles lawfully turning through a pedestrian stream. It occurs at a common two-phase signal and/or when a green arrow is provided for vehicles turning right. Although multiphase signals eliminate lawful conflicts between vehicles and pedestrians, longer pedestrian red signals in this case
Fig. 2 The effect of signal settings on pedestrian accident frequency at a one-way streets intersection.

(the $\rho$ factor in the models) can cause an increase of accident frequency exceeding gained benefits. Thus, question arises, when an exclusive phases for turning vehicles and pedestrians are justified. The expression $\exp(a_1 x_1 + a_2 x_2 \ldots)$ in the models (3) and (4) is transformed into $\exp(a_1 x_1) \cdot \exp(a_2 x_2) \ldots$, where each factor $x_i$ can be represented by the multiplier $\exp(a_i x_i)$. The signal timing factor $f = \exp[2.3(\rho-0.5)+3.58u]$ includes the signal lengths ($\rho$) and proportion of vehicles turning through a pedestrian stream ($u$). In Figure 3 the relationship between pedestrian red-to-cycle ratio $\rho$ and an accident frequency $w$ is shown for the various values of $u$. The graph in Figure 3 can be used to consider the effect of substitution of a common signal phase with an exclusive phase pedestrian safety for a given crosswalk or a whole intersection. It is also seen from the graph that when $u$ is in average greater than 0.3, the multiphase signals are justified at a channeled intersection for all reasonable signal lengths.

5. Accident prediction in non-stationary safety conditions

Although in developed countries a level of motorization is nearly stable, some long-term changes in traffic safety occur. This phenomenon is sometimes explained with a society self-learning process and with improvements of roads and vehicles. Traffic safety changes are enough slow to assume a steady accident frequency during
Fig. 3 The vehicle phase-to-cycle ratio $\rho$ and vehicle proportion $u$ impacts on pedestrian accident frequency.

Table 2
The comparison of regression models effectiveness in prediction of a number of accidents in 1989-90

<table>
<thead>
<tr>
<th>Model</th>
<th>Scaled deviance D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null model (sample mean)</td>
<td>153.3</td>
</tr>
<tr>
<td>Original model (3)</td>
<td>115.1</td>
</tr>
<tr>
<td>Model (3) with recalibrated slope parameter $k$</td>
<td>79.7</td>
</tr>
<tr>
<td>Model (3) with all parameters recalibrated</td>
<td>74.4</td>
</tr>
</tbody>
</table>
the time period to which a safety analysis and accident prediction models refers. In Poland a general safety situation is unstable, especially during the last few years. The question is, whether in non-stationary conditions the models like (3) and (4) should be used for an accident prediction. Developing models each year is cumbersome because it would require a large size sample due to high accident number randomness, particularly, in a short period of time. Moreover, the issue of a different value of accident frequency in next years still remains unsolved. The approach to a problem solution is presented below based on a sample of the studied crosswalks.

The accident prediction models (3) and (4) have been worked out based on the accident data in the five-year period 1984-88 with the assumption that the average accident frequency during this period remained steady. Now, the following four models are to be considered for the next two-year period (1989-90):
- a null model which is the average accident frequency in 1989-90,
- the original model (3) developed using the accident data in 1984-88,
- the model (3) with the slope parameter k recalculated for 1989-90,
- the model (3) with all regression parameters recalculated.

The models comparison made in Table 2 allows to formulate the following conclusions:
- the original model (3) has been found significant, although it is much less efficient in prediction of accidents happened in 1989-90 than in 1984-88,
- the model (3) with recalibrated slope parameter k=0.0135 has much lower scaled deviance D than the original model. The new k value is 13% higher than the original value which indicates that an increase in the number of accidents can not be wholly explained by the changes in values of traffic volumes and other model inputs. It should be mentioned that at the studied crosswalks, an increase of an average pedestrian accidents frequency between the two periods 1984-88 and 1989-90 is equal to 28%. Thus, the remaining 15% increase must be explained in the model through the traffic volumes increase.
- further recalculation of the remaining regression parameters reduces the scaled deviance D only by 1.1 per 1.l.o.f. which is not significant at the 10% level. It suggests that the local impacts (geometry, signals, traffic) were similar in both time periods. Thus, the change in an expected accident frequency on a given crosswalk might be referred to the change in overall traffic safety in the considered period of seven years 1984-90.

The above conclusions are important from the practical standpoint, since they enable to reduce a sample size in an accident prediction procedure for non-stationary traffic conditions. The suggested procedure is stated in the following steps:

1) Develop an accident regression model for an assumed period of few years. An accident and traffic data should represents the whole analyzed period.
2) Recalculate the slope parameter \( k \) for consecutive short time periods (of 1 or 2 year length) comprised by the basic time period. A data base used in each recalibration must be representative for a corresponding subperiod.

3) Predict the slope parameter \( k \) for a future years utilizing the \( k \) values found in the step (2) and using any forecasting technique.

The above procedure has been applied for the studied sample of 75 crosswalks. The models (3) and (4) presented in Section 4 are a result of the first step. In the second step, two-year periods have been defined in such way, that each two consecutive periods overlap by one year. The seven-year period 1984-90 comprises six two-year periods. The results obtained for the models (3) and (4) and the investigated sample are shown in Figure 4. The simple linear extrapolation has been used to find predicted values of the \( k \) parameter for the next 2-year period (step 3).

6. Concluding remarks

The paper presents the pedestrian accident prediction models developed for signalized crosswalks and intersections. The models have been used to highlight and quantify the effects of traffic and signals impacts on the pedestrian safety. The results are essential for the proper incorporation of the safety issue into economic evaluation of projects and the appraisal of alternatives.
A data collection phase in an accident factors investigation with large scale field measurements is usually the most costly part of a research project. The study has shown that short-term measurements carried on specially for a safety analysis or those conducted on a regular basis provide sufficient data base for accident regression models development. This finding is addressed particularly to the cases when traffic data records are of poor quality.

Poland is one of the countries where general traffic trends indicate a rapid safety deterioration during the last few years. The method for developing accident prediction models applicable in non-stationary conditions has been proposed in the paper.

References


CONDUCTING IN-DEPTH ACCIDENT STUDIES

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**Abstract**

In 1983 the Accident Research Unit at the Institute for Consumer Ergonomics began a major study, sponsored by the U.K. Department of Transport and three motor companies, to investigate the causes of injury to occupants in car accidents. This study has been under way for nearly ten years and the database of information is one of the most comprehensive of its kind in the world. This information plays a key role in establishing the priorities for safety research in the U.K., based on real life accident data.

This paper is concerned with the practical aspects of the collection and analysis of real life accident data. Issues include the establishment and maintenance of collaboration with police forces, hospital consultants and coroners; recruitment and training of staff; accident sampling; data quality control and large scale project management.

The case is also made for the need to establish a co-ordinated European database of accident information to facilitate the development of appropriate safety requirements and to set priorities for safety research in Europe.

**Introduction**

There is an array of techniques available for establishing the events leading up to and during real world accidents. These techniques range from the collection of basic statistical data, often collected by the police, to in depth studies in which vehicles' and occupants' performance in crashes are thoroughly and systematically investigated. Each method has benefits and disadvantages. Statistical data collected by the police can be used to obtain an accurate census of accidents but police officers are rarely suitably trained to be able to provide highly detailed data on drivers' perceptual abilities or injury biomechanics. Data from in depth studies can be used to examine individual crash cases or obtain a detailed perspective on types of accidents occurring, and can be very useful in providing an understanding of accidents. However,
in depth studies can be expensive and can fail to meet their objectives if not conducted in an appropriate manner.

In depth studies are currently in use by a number of organisations investigating the events that occur during the crash phase, including the National Accident Sampling System (NASS) and the Fatal Accident Reporting System in the USA, as well as the Accident Research Centre at Birmingham University and the Accident Research Unit at ICE Ergonomics, Loughborough in the U.K.. In addition, some research organisations and motor companies undertake specific studies of certain types of crashes when the need arises. There are also groups considering in depth studies as a way of establishing the pre-accident events more accurately.

This paper seeks to identify some of the key issues that those people conducting such studies have to deal with. It also highlights the need for a more co-ordinated approach that would link European vehicle safety decision making with a data collection system that supports the decisions and monitors the effectiveness of counter-measures.

This paper is based on ten years of in-depth accident studies at Loughborough University of Technology.

The Accident Research Unit Database

In 1983 the Accident Research Unit at the Institute for Consumer Ergonomics (now ICE Ergonomics) began a major study, sponsored by the U.K. Department of Transport, Ford Motor Company Ltd., Rover and Nissan, to investigate the causes of injury to occupants in car accidents (Mackay, G.M. et al 1985, Otubishin, A. & Galer, M.D. 1986). This study has been under way for nearly ten years and the database of information is one of the most comprehensive of its kind in the world.

The database describes the collision damage to over 5,000 vehicles and the 32,000 injuries of over 9,000 occupants. The vehicles included in the sample are examined by a team of accident investigators. They use a recording schedule which includes data about vehicle damage, performance of secondary safety features and potential occupant contacts. The information about occupant injuries is collected from collaborating hospitals and coroners as well as from the occupants themselves. The task of relating the injuries to vehicle performance and the injury mechanisms is carried out by specialists in the team. Analysis of this extensive database is undertaken for the project sponsors and for other organisations.

Key Issues in Establishing an Accident Research Unit Database

In order successfully to establish and maintain an accident database it is essential to bear in mind at all times that this is a collaborative venture, that
each party has a vital role to play and yet none of the parties actually has to take part in the study.

One must establish and maintain collaboration with police forces to ensure that notification of accidents is accurate, consistent and timely. The commitment to participate in the study must be institutionalised in each force and become a commitment for people at all levels in the organisation.

Hospital consultants frequently take part in the study out of a genuine commitment to the aims of the study, namely research into the reduction of injuries in traffic accidents. Consultants from a wide range of disciplines including accident and emergency departments, orthopaedic departments, neurology departments and so on all need to be involved, with the accident and emergency department consultants often playing the key role in processing of the injury information and enabling access to more detailed information from the other specialists as the need arises. The hospitals are the primary source of information on seriously injured occupants. They must be prepared to provide detailed and accurate information in a timely manner over long periods of time. Not only are the consultants involved, but their staff at all levels play a key role in retrieving and collating patient injury information.

Coroners are the major source of information about fatally injured occupants and they play a key role in providing access to the highly detailed coroners' reports.

Recovery garage proprietors do not have to allow access to the vehicles on their sites and yet are often sufficiently enthusiastic about the study to offer the cold accident investigator a hot cup of tea at times!

The establishment and particularly the maintenance of collaboration with these people can be done successfully by providing frequent feedback thorough presentations on the progress of the work and interesting new findings, by providing advice on special topics when the need arises and by constantly keeping the project to the forefront of their minds.

Recruitment and Training of Staff
Accident investigators are a rare breed and do not come ready trained from a relevant course. They have to be recruited with certain essential skills and then extensively trained in vehicle examination techniques, photography, aspects of mechanical engineering and biomechanics. There are no clear guidelines as to what makes a good accident investigator and so recruitment can be a problematic activity for a team. In addition, the career prospects for a highly trained accident investigator are not clear, as there are few other establishments which require their skills. This point is also well made by Richardson, F. G. and Costello, F. B. (1985) who say "..... the backbone of the system (would really be) a sizeable group of reasonably qualified, modestly
paid technicians who would become experts in a field with an uncertain career path, little recognition and even less job security".

People able to interpret the data obtained from an investigation of a vehicle and the associated injury data are even rarer, as are people with the necessary computing skills to design and operate a complex multi-faceted computer database.

It is very important that the accident investigators, whether in one team or, as in the case of Loughborough, in a number of teams located around the U.K., see their role in the context of the whole study and realise why each part of the study, each item of data collected, is vitally important to the success of the whole project. Motivation can be hard to maintain when the investigators are out in the cold and wet for some time during each year.

Accident Sampling
The sampling procedures for accidents to be investigated are critical to the usefulness of the data obtained in the study. Unless the sampling strategies can be related to the population of accidents it is not possible to use the data in any predictive manner. If the sampling procedures are altered during the lifetime of the database this can have significant consequences for the reliability and validity of the analyses and the predictions from the data. In the case of the Accident Research Unit database the sampling is based on the severity of injury and whether or not the vehicle was towed away from the scene of the accident. The purpose is to include accidents with a reasonably high impact severity. However, relating this to national statistics is not straightforward as records of tow-away accidents are not available.

Data Quality Control
Large quantities of data on accidents, vehicles and occupants are collected over long periods of time, by a variety of people with different levels of skill and experience. The control over the quality of information gathered and eventually entered onto the database is crucial for the usefulness of the information. Material comes from the collaborating police forces, hospitals and coroners in a variety of forms, more or less complete and more or less consistent. Sometimes it is impossible to read the police officer's handwriting, sometimes there are more data than there are reported occupants in a vehicle, sometimes the data from different sources do not agree. Data are also collected at a number of sites. The data available at Loughborough are collected by nine different teams including seven teams employed by the Department of Transport, rather than Loughborough University. It is easy for different teams to record the same information in a number of ways, just as it is possible to make a variety of interpretations from the same data. To ensure consistency of data collection and recording communication between teams is vital, and a structured approach to the search for systematic differences can be particularly fruitful. It is also beneficial for one person to take responsibility for the data quality across a
In 1985 Richardson and Costello reported that 20% of the NASS resources were devoted to quality control. Tact and diplomacy are helpful characteristics for this individual. All these issues must be addressed to ensure a high degree of data quality.

**Data Analysis**

The database contains both qualitative and quantitative data, as well as objective and subjective data. This is because the information comes from a variety of sources including vehicle investigations (e.g. measurements of vehicle crush, performance of seatbelts in the crash); coroners' reports (e.g. injuries observed during the examination); allocation of injury causation and injury mechanisms (e.g. occupant head contact on the steering wheel); questionnaires to occupants (e.g. seating position, occupant size, whether or not a seat belt was worn at the time of the accident). In order correctly to interpret the data the data analyst needs to understand how the data are collected, recorded and coded.

The establishment and smooth running of large scale in-depth studies can easily become an end in itself and the issues discussed above can be substantial. This is usually recognised by sponsoring organisations who consequently specify the project objectives in general terms. One consequence of this is that the analytic output from these studies can be seen as of less importance than the gathering of the data. It can also occur that funding for data analysis is not available either from the original funding organisations nor extra-murally. As a consequence the data can be significantly under-utilised. Non-specific research objectives create an additional difficulty when judging the value of the study. In the absence of specific analytical requirements a study has to be judged in terms of, for example, numbers of accident cases or numbers of coding errors. Project assessment can be based on criteria which are different from the original project justification. This discrepancy can cause difficulties for the project sponsors, the contractors and for the project staff.

**Large Scale Project Management**

As with any large scale project the job of project management is crucial. In the case of the Accident Research Unit at Loughborough the vast majority of the people on whom the success of the project relies, such as the police, hospital consultants and coroners, are not directly responsible to the Project Manager, they co-operate with the project voluntarily. They have other priorities, time scales and motivations. Other critical project management issues include: the nature of the funding, which in the case of the Loughborough study is funded by a consortium comprising the Department of Transport, the Transport Research Laboratory, and three motor companies, Ford, Rover and Nissan. It is necessary for all the members of the consortium to agree the terms and conditions of the contract. The length and continuity of project and staff contracts can also cause problems as they are usually of a fixed term nature and considerable discussion and negotiation accompanies
the renewal of the contract each time. When it is not known for how long the study will be continued it is difficult to retain staff who have become trained in the specialist skills required for the study. The management structure, bearing in mind the consortium based funding and the collaborative nature of the enterprise has to be very careful designed to ensure that all parties feel satisfied with the arrangements. Within the study the relative status of the individuals involved and their perception of what constitutes due recompense for their efforts can be a significant matter. The sheer size of the operation can also be rather daunting.

The Need for a Co-ordinated European Database of Accident Information

There are other organisations in Europe and elsewhere that collect and analyse information about primary and secondary safety aspects of road accidents. However, there is no overall consistency of data collected, of data collection techniques or of analysis procedures. This means that it is not possible to review the accident-related trends and patterns across Europe or elsewhere in the world in a consistent manner.

The introduction of European Whole Vehicle Type Approval in 1994 will serve to strengthen the European car market. Decisions over vehicle design and safety performance have been made at European level since the 1970s. This centralised activity has not been supported by an equivalent system that evaluates the problems of safety in European vehicles. If any accident research is done at all it is usually financed by individual governments or manufacturers. While this research may reflect the needs of the individual funding group it may not be accepted by other European countries.

There is a lack of co-ordinated basic information on road user casualties. For example surviving casualties are not counted in a uniform way in the twelve countries; European seat belt use rates are not known; neither are the wearing rates for motorcyclist helmets. There is also no representative data describing the patterns and causes of European road user injuries. The effect of the variety of traffic conditions in the member states on the numbers of accidents is also unknown, as is the effect of speed limits and their enforcement. This makes the assessment of safety priorities difficult to establish and there is no way in which the introduction of safety counter measures can be monitored across Europe.

The introduction of side impact and partial overlap protection to cars, pedestrian protection, motorcyclist leg protection systems, speed limiters on trucks and buses, and uniform speed limits across countries are all major safety items. There is currently no way that the effect of these on the complete European accident population can be adequately assessed.

This lack of a uniform European data set has served to delay or prevent many pieces of safety regulation. Frequently the lack of real world accident data is
taken to infer that no problem exists, while in reality there are no data because there is no group that collects the data. Examples are the inordinate time taken to implement side impact counter measures and the inability to agree on the need for a face friendly steering wheel.

In contrast the USA has an accident data collection system that matches with the needs of the safety targets of the NHTSA. The USA has a General Estimates System (NHTSA, 1990) that uses a sample of around 46,000 accidents each year from 60 sites. These crashes represent the estimated 6,500,000 accidents nationally and supply basic data on roadway, vehicle and road user characteristics. These data are supplemented by a greater level of detail collected for all fatal crashes within the Fatal Accident reporting System (NHTSA) and a highly detailed data set collected within the National Accident Sampling System (NHTSA) that collects data on 7000 light passenger vehicles each year. The centralised consistent approach of the USA accident data collection system has facilitated the early development of more demanding safety requirements and a safer vehicle population.

There is a strong need for a European procedure for systematically collecting and analysing information, in a co-ordinated fashion, on the causes of accidents and the secondary safety effects on injury in accidents. The experience gained at Loughborough and supported by the NASS experience indicates that the establishment of large-scale, in-depth accident investigation studies is a complex and demanding activity, but one which provides major benefits.

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SHIP COLLISIONS WITH OFFSHORE PLATFORMS

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ABSTRACT
The chance that a fixed platform is rammed by a passing ship is studied using a fault tree of technical or navigational events which lead to collisions. It is found for the North Sea that the chance of a collision can be appreciable for a platform located near a busy shipping lane but relatively insignificant for a platform in an isolated location, far from shipping lanes. Appreciable in this context describes a chance comparable to that of a major fire on an offshore platform.

Old and flag of convenience ships are involved in most of the collisions.

In the course of the literature survey, it was found that many mariners use charted offshore platforms as navigational aids; they therefore approach close to them for the sake of positive identification. One practical means of reducing the chance of collisions would be to install racons on navigationally significant platforms so that they could be identified on a radar screen from a distance; this would alleviate the need for this close approach.

A second effective approach is to install a traffic guidance system for groups of platforms near busy shipping lanes. Experience with such a land-based guidance system in the Dover Strait has been very rewarding.

INTRODUCTION
Collisions have occurred between passing vessels and offshore platforms for some time. In the North Sea, a fixed structure in Dutch waters which had just replaced a lightship was rammed by a coastal merchant ship in the late sixties. A more bizarre accident occurred in the eighties when a submerged German submarine rammed a fixed platform in the Norwegian portion of the North Sea. Ship designers allow for collisions in their designs; the watertight bulkhead behind the bow of a ship is a consequence of this.

Platform designers, on the other hand, are also obviously aware that there is a finite chance that a platform will be hit by a passing ship but little has been done to systematically quantify this chance.
METHOD SELECTION
Unless further assumptions are made, the direct approach effectively treats all platforms or ships equally; each has an equal chance of unexpectedly meeting the other. This makes the evaluation of the risks to a single platform -- which may be quite near to a busy shipping lane, for example -- rather difficult. Restricting the chosen data so as to include only such specific platforms runs into the problem of having too small a statistical basis for making dependable predictions.

The fault tree method is not perfect either. While the input data generally have a more reliable statistical basis, the method includes another pitfall: The quality of the end result depends upon the fault tree including all of the possible error sequences which can lead to such collisions. An advantage, on the other hand, is that this approach can be applied to a single specific platform and it is also easy to evaluate the consequences of possible accident prevention measures.

FAULT TREE APPLICATION
This fault tree approach is used here. The basis of a fault tree for this problem is the combination of events using AND and OR logical operations to lead to a collision between the passing ship and the fixed platform. Such fault trees can be built up in a number of stages. A very rough form is shown in figure 1. The 'input' blocks are as follows:

A. Overall collision course error
B. Platform not sighted
C. Platform protection failure
D. Last-minute recovery failure
E. Collision due to technical failure

It should be obvious that for a collision to occur, events A and B and C must occur to result in an intermediate block 'Collision imminent' in figure 1. Further, if the last minute recovery, D, fails as well, then a collision will be unavoidable. In addition to this, a collision can occur in quite another way: via a technical failure of the propulsion or steering systems; the ship can then drift against the platform during a storm, for example. This event E, can be combined with the result of D and 'Collision imminent' using an OR operator as in figure 1.
A properly running computer program will always provide an answer; the reliability of such answers from this type of program can be checked in two ways: First, a rather degenerate set of input values (some are always false while others are always true) can be used so that resulting chances can be checked by hand. A second check is to vary specific input chance distributions slightly to test the sensitivity of the model. This can be useful, too, to help judge the proper trade-off of detail versus clarity mentioned above. If the outcome is very sensitive to small changes in one input item, then that item is a candidate for further refinement.

An advantage of the fault tree method as programmed for this study is that data is retained about the ship (type, size, and flag) and sequence of events which lead to each actual collision - a true final event. By studying these paths through the fault tree, it is later possible to ascertain which groups of ships and/or initial events have contributed the most to the actual occurrence of collisions. This information is, in turn, very useful for indicating which improvements to operations can be expected to have the highest benefits.

Once a promising improvement had been found, a new computer run was carried out with modified 'input' data distributions in order to quantify the statistical effect of that improvement more exactly.

FURTHER PROCESSING
In all of the computations carried out so far, it has been assumed that the vessel is in such a position that a collision can be more or less expected. Obviously, not all ships passing along a shipping lane pose a threat to a platform; this has been taken into account manually by adjusting the computer results to account for the portion of the (known) total shipping traffic which is in a position to present a collision risk. This is done on the basis of the ratio of lane width to the distance from the lane centerline to the platform.

LIMITATIONS
This study has been restricted to include only ships which move along rather well-defined traffic lanes. This eliminates fishing vessels, sailing yachts, and naval ships from the analysis. Also, this study restricts itself to passing ships.
The 50% of all ships more than 10 years old were involved in 88% of the collisions.

Little influence of the ship type on the collision statistics was found.

82% of the collisions occurred in fog; seven times as many accidents occur at night. 12% of the accidents occurred under storm conditions, while storm conditions (as defined here) only occur 3.3% of the time in the North Sea.

The sensitivity of all this has indeed been checked as well. The resulting chances can vary by a factor of up to five. While this factor seems high from a scientific point of view, it can be included when trying to evaluate 'best possible' and 'worst case' situations.

**COLLISION CHANCE REDUCTION**

It should be obvious from the above that it can be relatively lucrative - from an insurance premium point of view - to try to reduce the annual probability of a collision unless the platform is very remote to shipping lanes.

In view of the fact that many ships approach close to platforms for the sake of a positive identification, it can be appropriate to take actions which make this approach less necessary. One quite simple and inexpensive step could be to equip each platform with a racon device so that its identification would become visible on the ship's radar screen. This would usually preclude the need for visual identification, and would reduce the overall collision risk by a factor of 5.7. Such a measure does not involve personnel at all; it is equally effective for manned and unmanned platforms.

A more far-reaching (and effective) measure can be the cooperative set-up of an active traffic control system for the areas surrounding a group of platforms. This will involve personnel who will actively follow the movements of ships in the area and provide advice to those which may be getting into trouble - either with a platform or with other ships. Experience in the Dover Strait has been that once such a system became well-known there, mariners tended to count on its help; the collision chance there was reduced significantly.
Overall collision course error
Platform not sighted
Platform protection failure
Last-minute recovery failure
Collision due to technical failure

AND

Collision imminent

AND

Collision due to navigational failure

OR

COLLISION!

Figure 1 Overall Fault Tree
Figure 2
Events Leading to Ship on Collision Course
All marine catastrophes (including collisions) can lead to any combination of the following three types of risk: to persons - either those directly involved or as by-standers such as yachtsmen; to property, or to the environment. Interest here is focussed on the factors which determine the chance that a passing ship rams a platform. Various perceptions of risk are discussed in [1].

APPROACH METHODS

Unfortunately, direct data on the risk of collisions between passing ships and offshore structures is scarce and therefore of limited usefulness; a direct approach by a statistical analysis of data such as that available in [2] will may prove incomplete or will often be too general and reveal little or nothing about the effects of collision chance alleviation measures.

On the other hand, there are now over 250 offshore platforms in the North Sea alone; while certainly not all collisions with such platforms have been reported, the fact that there have been no major disasters cause by ramming of these platforms is a significant piece of statistical information. Some use [4] this knowledge to help specify the probability characteristics of ship - platform collisions.

An alternative to the direct or overall approaches starts with statistical data on ship operational details (such as not having adequate charts on board). Because such records are much longer -- they have been recorded in all sorts of ship accident reports for generations -- their statistical values are more reliable. These data are linked to ship-platform collisions by constructing a fault tree for events which could lead to a such a collision.

A fault tree is utilized by selecting sets of random values consistent with the background statistics and following through the fault tree to see if a collision occurs. Statistics of the collisions themselves can be generated by repeating this process a large number (say 10 000) times on a computer. It should be noted that the statistical data involved is of the form: "What is the chance that a ship has inadequate navigational charts" - to continue with the example used above. The value, itself, in any given simulation of a ship passage will be either true or false; fault tree computations involve purely logical variables.
The limitations of fault tree analysis discussed in the approach methods section can cause imprecision in the absolute value of the collision statistic generated. On the other hand, since possible systematic type errors will remain rather constant, relative statistical values will remain valid. This method is most suited to comparing situations at different locations or relatively evaluating preventative measures. Absolute values of collision probabilities are less reliable.

THINGS LEARNED ALONG THE WAY
It appears from the literature that fixed offshore platforms are often used as navigational aids by passing ships. Since their locations are indicated quite precisely on charts, they are usually visible from long distances and there is sufficient water depth around them, they are attractive as navigational aids. Unfortunately, many offshore platforms look pretty much alike. Mariners must often approach a platform quite closely for exact identification. Additionally, other mariners still consider platforms to be curiosities which demand further close inspection. They often quite nonchalantly violate the safety zone set up for such platforms by international agreement.

RESULTS
This fault tree model has been used with platforms at five different locations in the Dutch and English North Sea; one North Atlantic location was used for comparison purposes.

On the quantitative side, absolute collision chances ranged from a low of 5.1 E-6 to 0.032 per year; the first value seems rather insignificant, the second one is shocking! More important is the relative value; a platform near a busy shipping lane has 6000 times as much chance of being hit than a single platform in an isolated sea.

Much additional insight has been gained by comparing results from the six locations. The distance from the traffic lane centerline to the platform (expressed in terms of the lane width standard deviation) is very important in determining the resulting overall probability of a collision. If the platform is located more than 5 lane widths (standard deviations) from the lane center, then the chance of a collision from a passing ship becomes negligible simply because the number of ships in a potentially dangerous position is so small.

In the locations checked here, the 30% of all ships flying a 'substandard' flag caused 50% of the collisions.
There still remains the problem of determining the statistical distributions for each of the 'input' events A through E; these cannot be found in the literature any better than data on collisions, themselves. The solution to this is to 'set' the values for events A through E, above, by means of additional, more refined fault trees. One such tree leading up to event A is shown in figure 2.

A conflict between level of detail on the one hand, and ability to oversee the problem via a fault tree on the other hand always remains. While fault trees could probably be constructed to determine each of the 'input' items in figure 2, this might confuse the issue more than clarify it. Also, the data necessary for the 'input' items at the level of figure 2 has been found in the literature.

INPUT DATA
The resulting list of 'input' items and the associated chance that they occur were 'distilled' from more than 30 publications in the original report [1]. It appears from the literature that the:
- Type of ship (general cargo, ferry, etc.),
- Size of ship,
- Flag of registry, and
- Age of ship

all influence the chance that many of the 'input' values are true. These influences are included in the simulation by adjusting the 'input' item chances using correction multipliers dependent upon the four factors listed. This puts an adjustment layer at the beginning of the fault tree analysis to store and apply these correction factors to the basic chance values. Additional data on the joint (type, size, flag and age) statistical distribution of ships passing the area in question are needed, but can be found or estimated quite readily from ship traffic surveys or harbor statistics.

Weather conditions data - chance of storms and of fog - are obviously important and included in this analysis, too.

FAULT TREE COMPUTATIONS
The fault tree and associated computations and bookkeeping were programmed in FORTRAN and run on a MicroVAX II computer. A typical execution time with 10 000 ship passages was less than 5 minutes; this was sufficiently fast to allow many different situations to be tested.
CONCLUSIONS
A complex chain of events lead to collisions between passing ships and offshore platforms.

Certain categories of ships are more strongly represented in the accident statistics than their numbers in the shipping fleet would lead one to expect. Ships with a flag of convenience and older ships are in this category.

During the literature study for this project, it was found that many mariners purposely pass close to offshore platforms to identify them, thus providing themselves with a navigational check.

Most accidents occur when visual observation and identification is limited by darkness or fog. Improvement of other platform identification means can reduce the number of accidents under all conditions. A simple, inexpensive means of facilitating identification from a distance is to equip significant platforms with a racon so that they can be easily identified on a radar screen. This will then preclude the need for the close approach required for visual identification.

A second, more far-reaching (but very practical and effective) means of reducing the collision chance would be to install an active traffic guidance system for ships in the area around (groups of) platforms. Experience with a similar type of system installed along the Dover Strait has reduced the number of collisions by roughly a factor of 4 since installation even though the traffic density has increased.

REFERENCES
Note: this report includes over 30 references.


Safety of Platforms in the North Sea

by

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Abstract

This paper describes the development of a method to determine the probability of a collision of a vessel with a platform. The method has been applied on the platforms in the North Sea, and it was found that the maximum recurrence period for a collision between a vessel and a platform located in the North Sea was about 10 years, if the failure rates were based on the current record of casualties. Permission was granted by Mr. J. Pulles, North Sea Directorate of the Rijkswaterstaat, Ministry of Transport and Public Works, granted permission for parts of the MANS Shipping Traffic Module to be used for this paper.

1. Introduction

A traffic model describing the traffic in European waters was developed during the European project COST 301. This model was used to calculate the probability of a casualty as a function of a traffic parameter and to assess what measures could be taken to reduce the number of casualties. The concepts of the COST 301 model were used to develop the "Traffic Module" of the so called MANS (Management North Sea) model. This model has been designed to determine the effect of shipping activities in the North Sea on the water quality. An interesting by-product is that the basics of a traffic model can be used to make some simple estimations of the probability that shipping activities might result in pollution. If a ship collides with a platform regardless of speed it is highly probable that large damages are inflicted to the platform and that these damages might result in extensive pollution. The ship also might sustain heavy damage and there will be a large probability of pollution, fire and the eventual loss of the ship. How often do such incidents occur and what can be done to prevent them? A number of studies exists at risk reduction in relation with platforms. These studies generally use a fault tree approach and determine probabilities of the events in which the sequence can be broken down. A large difficulty is the determination of the probabilities of events. Generally the results of such studies indicate probabilities of collision risk for a platform that are unrealistically high, see [1,2]. The present method is applied to determine overall failure rates on the basis of casualty records and traffic parameters, these fault tree methods can be put into perspective by using the failure frequencies in a relative rather than an absolute sense. The fault tree approach may be beneficial to determine the most cost-effective risk reduction measures. Again one should be
careful about using measures that have an impact beyond the immediate area of concern.

Such an example is the racon, which is an effective means of detecting isolated platforms. The presence of a racon on each platform when these platforms are in close proximity to one another is extremely confusing and probably counter-effective. Navigators' PPIs should not be cluttered with racons. One or two racons on a PPI with a range of 12 nautical miles is sufficient for identification of one platform. If a navigator identifies the platform with the racon, he can determine the relative positions of other platforms. If the navigator is absent or negligible a racon will not help, anyway.

This paper will discuss briefly the development of a traffic model for the North Sea. It will be shown that such a model can be used to determine a relevant traffic parameter to relate traffic flows to casualties. On the basis of a global "navigational error rate" or a global (engine) "failure rate", determined outside the model on reported engine failures, it is possible to redistribute the risk for each platform or group of platforms. The relevant formulae are presented and some results are shown.

2. Traffic Model North Sea

The traffic model of the North Sea (one of the Modules of the MANS model) consists of the following elements:

- (i) a route structure
- (ii) ship matrix definition
- (iii) calculations

(i) A route structure has been designed based on the assumption that each port in the North sea is connected with another in the North Sea as well as with the exit and entry points in the North sea such as:

- the Dover Straits
- the Skagerrak
- the Kiel canal
- the Pentland Firth
- the stretch of water between the Orkneys and the Shetlands

Routes generally are designed from pilot station to pilot station. Some pilot stations serve more than one port, while in other cases two pilot stations serve a single port. The pilot stations are determined on the basis of the British Admiralty Pilots.[3].

When a route is determined between two pilot stations is established, the following procedure has been used:
- the existence of T(traffic) S(eparation) S(chemes) in the North Sea is respected and the Rules (part of the Rules for the Prevention of Collisions at Sea) to use a TSS are followed by the navigator.
- the existence of Deep Water Routes in the North Sea is acknowledged and the recommendations to use them are followed by the navigator.
- for each category of vessels, the available depths are checked and, if necessary, the route is adapted.
- each route consists of a number of links, a link being a straight line between two points. These points are called waypoints. In total about 3,000 links have been established.

ad(ii) Traffic flows can be broken down into a matrix specifying the type and the size class of each ship. A ship type can be determined by a unique identifier (the Lloyd's number of each ship) which provides access to a database containing the main particulars. A ship's size can be measured by various means. The most common of which is the gross tonnage of a ship. An example of the ship matrix is given in Table 1.

ad(iii) On the basis of the voyages of all ships in the North Sea, it should be possible to determine the intensity of the shipping flow on each link. A voyage (for the purpose of this study) states that a vessel with a certain Lloyd's number has departed from a certain port to another port within a given time interval. (This interval is often selected to be one year). If a voyage is between two different ports, it is possible to assign this voyage with a ship of a given size and a given type to each link of the route structure. If all voyages in the predetermined time interval are processed, the intensity of the traffic flow on each link is known. The ship matrix indicates the composition by providing the number of ships using that link in each matrix cell. The allocation of ships to links is illustrated in Figure 1.

Normally the traffic model provides the following basic data:
- the composition of the ships using a link
- the number of vessels that is present at any one time in a given area by determining the length of each link in the area of interest and the intensity
- the number of ships that passes a given geographical point at different distances
- the number of ships that passes a given geographical line.

These calculations are the basic traffic calculations for a number of applications such as:
- calculation of encounters to determine casualty ratios (i.e. the number of collisions per 100,000 encounters, the number of groundings per 1,000,000 nautical miles)
- calculation of air emissions in a certain area as a function of the characteristics of the vessels and their engines
- collision analysis of platforms
- external, marine-related, threats for pipelines
3. Prediction of Platform Collisions

Two different situations will be considered:

- a ship is on collision course with a platform and a navigational error occurs. This error is undetected until the point of no return and the ship collides with the platform. The collision may be at a high or a low speed depending on the time lapse between the point of no return and the implementation of corrective action after the detection of the error. This mode will be called the navigational error mode.

- a ship in the vicinity of a platform experiences a failure in the propulsion engine or in the steering equipment, since the ship slowly becomes uncontrollable as it loses speed and the combined effect of wind, waves and currents may carry it towards the platform. If dropping an anchor will not help and the repair time of the engine is insufficient, the ship may collide with the platform, generally at a low speed. This mode will be called the engine failure mode.

Collisions involving ships that are alongside a platform such as supply vessels and anchor-handling tugs are not considered here. In practice these collisions can cause extensive local damage to both the vessel and the platform. The impacts will impair the structural integrity of the platform in only rare cases.

Both situations may occur and the following remarks can be made:

- In the navigational error mode, the navigator may have left the bridge and upon his return he finds that the platform is threatening the safety of the vessel. He will do whatever he deems necessary to avoid the platform by initiating an emergency turn or by giving "Full Astern". Since navigators are rarely absent for long periods, he may be back before impact. In cases where the navigator returns to the bridge, realizes what is happening and implements a certain escape manoeuvre, the impact speed may be reduced.

- Heart attack, drunkenness and sleep deprivation are contributory factors to the navigational error mode. Other infrequent factors are: criminal negligence of duty and suicidal behaviour.

- If the impact speed is high, it is very likely that a fire will start, possibly igniting the vessel's cargo if it is flammable, should one be be involved in the collision.

- Some measures might avert a collision in the engine failure mode. It might be possible to drop an anchor during the drifting process. If one takes the design conditions of an anchor and the anchor chain into consideration, the speed of the vessel in relation to the ground should not exceed a certain threshold speed. A higher speed will invariably mean that the anchor cable parts. Another method might be to pump out the anchor and to use it as some sort of drag. This might change the direction in which the ships drifts. In some cases, tugs or supply vessels are in the vicinity and these can be used to assist the ship avoid the platform.
3.1. High speed collisions

A simple estimation of the probability of a platform collision in the North Sea depends on the following factors:

- the positions of all the platforms in the North Sea and an indication of their size.
- the link structure in the North Sea and the intensities and composition of the vessels using these links.
- some of the physical characteristics of these vessels.
- statistical climatological data regarding wind directions and wind speeds.
- failure rates for propulsion and steering engines (in fact, the probability distributions of MTBF (Mean Time Between Failures) and MTTR (Mean Time To Repair)).
- the knowledge that, since 1965, one drifting collision has occurred between a vessel and a platform in the North Sea. A high speed collision has not been recorded.

The first platform in the North Sea was installed in 1965; there are now more than 300 platforms. Since 1965, more than 3000 platform years have passed, see Figure 2.

A method to determine the number of collisions to be expected is based on the calculation of a parameter $R$. This quantity is defined as follows:

$$R = \sum_j \sum_i \frac{n_{ij}}{d_{ij}}$$

(1)

In (1) the following quantities have been used:

- $R$ is the traffic parameter for all platforms in the North Sea (weighted passages)
- $d_{ij}$ is the distance from link $i$ to platform $j$
- $n_{ij}$ is the number of vessels that passes platform $j$ on link $i$ at a distance $d_{ij}$

Equation (1) provides a parameter of risk that is directly proportional to the number of ships on a link and inversely proportional to the distance of passing.

The number of collisions can be computed using the following equation:

$$\# \text{Coll}_{\text{hard}} = NER \times \sum_t R_t$$

(2)

In (2) the following quantities have been used:

- $\# \text{Coll}_{\text{hard}}$ is the number of collisions in the North Sea between platforms and ships from the time that the first platform was erected to the present.
- $R_t$ is the traffic parameter for all platforms in a given year $t$.
- $NER$ is the "navigational error rate" of the navigator.
To determine NER the following method has been applied. It is realized that, so far, no full speed accident has occurred. This suggests that, with a confidence level of 95%, a maximum of three collisions could have happened. This would mean that an estimation of \# Coll\_hard is available and, consequently a value of NER would be available. The value of NER is important to determine the recurrence period for collisions with all platforms, with platforms of a given nationality or platforms belonging to a certain offshore company, or even a single platform.

3.2. Drifting Collisions

The determination of the number of drifting collisions is based on the concept of a danger mile, which is the part of a link from which a drifting vessel of a given length is able to hit the platform, given a certain wind speed and wind direction. The configuration of a platform is represented by an equivalent circle with a radius R. The distance traveled downwind cannot, however, be more than the drifting speed that will be generated by the wind force multiplied by the time of the engine failure (MTTR). If the platform is beyond this distance, no collision will result and consequently no danger miles are produced. The danger miles should be multiplied with the failure rate under different Mean Time To Repair-values in order to obtain the number of drifting collisions.

\[
\# \text{Coll}_{\text{soft}}(A) = \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n \left(2R_i + L_m\right) \int_0^1 \frac{1}{\sin \phi_{i,k}} \, d\phi_{i,k}
\]

In this equation is:

- \# Coll\_soft(A) is the number of drifting collisions with all platforms in a predefined area A
- index i refers to the number of platforms in area A
- index j refers to the three different failure rates connected with a MTTR of 1, 2 or 6 hours
- index k refers to the links at distances less than the maximum drifting distance
- index l refers to the number of velocities of wind to be considered
- index m refers to the cells of the ship matrix, representing the traffic flow on each link.
- index n refers to loading conditions of the vessels of the traffic flow

FR\_j is the failure rate (MTBF) associated with a MTTR of respectively 1, 2 and 6 hours.
\( p_i = \) the probability that a given wind speed \( v_i \) occurs

\( p_{nf} = \) the probability that a ship of class \( m \) is in a light condition (This value is generally 0, but for the ship types OBCs, tankers and bulkcarriers, this value is 0.5).

\( R_i = \) equivalent radius of the platform based on length and width

\( \phi_{i,k} = \) the angle between the wind direction and the direction of the traffic flow on link \( k \) for platform \( i \)

Only the links are considered for which the drifting distance is less than:

\[ V_{\text{drift}} \times \text{MTTR}_j \]  

(4)

In this formula \( V_{\text{drift}} \) is the drifting speed for a given ship under a selected wind condition. The number of links that satisfy that condition is called \( k \).

The wind characteristics have been simplified to a distribution of wind speeds irrespective of the wind direction, based on statistics of a light vessel in the Southern part of the North Sea. It is assumed that the distribution of the wind directions is uniform. (This is accurate for lower wind speeds but not very accurate for higher wind speeds).

In any case:

\[ \sum_i p_i = 1 \]  

(5)

The drifting speed of a given vessel toward the platform is an important parameter. It is assumed that the vessel will be broadside against the wind and that the drifting speed will be determined by the ratio between underwater ship area and windage area. This ratio will vary between wide limits for vessels having a pertinent full draught and a pertinent ballast draught, as is the case with tankers and bulkcarriers. Consequently, we must consider two cases for these types of vessels.

Wave action also is important. It is assumed that wave height depends on wind direction and that wave direction coincides with the wind direction. These assumptions simplify the problem to a large extent, but they will not affect the order of magnitude of the final results.

The drifting speed for a given vessel with a given loading condition is shown in the following equation:

\[ V_{\text{drift},i,m,n} = \left( \frac{\rho_\text{air}}{\rho_\text{water}} \right) A_{L,m,n} / (L_m T_{m,n}) c_{\text{wind}} / c_d v_i^2 + H_i^2 g / T_{m,n} c_{\text{wave}} / c_d)^{0.5} \]  

(6)

The following symbols have been used:
\( v_{\text{drift},m,n} \) is the drifting speed of a given vessel \( m \) with draft condition \( n \) for a wind speed \( I \).

\( \rho_{\text{air}} \) is the specific density of air

\( \rho_{\text{water}} \) is the specific density of water

\( A_{Lm,n} \) is the lateral windage area of ship \( m \) with draft condition \( n \)

\( L_m \) is the length overall of ship \( m \)

\( T_{m,n} \) is the draft of ship \( m \) under draft condition \( n \)

\( c_{d,\text{wind}} \) is the lateral wind resistance coefficient of ship \( m \)

\( c_d \) is the lateral resistance coefficient of the underwater body of ship \( m \).

\( v_I \) is the wind speed in class \( I \)

\( H_I \) is the significant wave height of the wave field assumed to be generated by wind speed \( I \)

\( c_{\text{wave}} \) is the wave drift coefficient

\( g \) is the acceleration due to gravity

4. Some results

Using the results of the traffic model the number of times vessels pass platforms in the North Sea has been determined. Approximately 1,100,000 passages at a distance smaller than 5 nautical miles may be expected, annually. About 600,000 of these passages occur on the Netherlands Continental Shelf and about 400,000 passages on the UK Continental Shelf. Norwegian and Danish platforms are generally in areas with lower traffic densities. See Figure 3.

Using the navigational error rate (NER) as determined in 3.1 on the current casualty record of collisions between vessels and platforms, the maximum probability of a high speed collision between a vessel and a platform may be estimated as follows:

- a platform on the Netherlands Continental Shelf 0.121 / year
- a platform on the UK Continental Shelf 0.117 / year
- a platform on the Danish Continental Shelf 0.011 / year
- a platform on the Norwegian Continental Shelf 0.007 / year

This has been depicted in Figure 4.
The relative average probability of an individual platform being involved in a high speed collision on the four different Continental Shelves is given in Figure 5. If the probability of a Norwegian platform, being hit, is set on 1, the probability of a Danish platform is 1.35, a UK platform 3.18, and a Netherlands platform 6.26 times higher than the Norwegian probability. These values seem to be very high. One must take into account that a number of platforms in the North Sea are in separation zones of Traffic Separation Schemes. The model used to distribute the probabilities (equation (1)) does not discriminate between a ship passing in the absence or the presence of a Traffic Separation Scheme or a Deep Water Route. It is reasonable to assume that the TSS will have some effect on the navigator, with respect to his absence on the bridge. Consequently, this will affect the NER in a TSS. It is not unreasonable to expect that this NER will be an order of magnitude lower than in an area without a TSS. On the other hand the density of vessels expressed in #ships/nautical mile$^2$ might also play a role in the NER. A navigator will tend not to leave the bridge and start other work if his watch is busy. Consequently it is important to model the values of NER in accordance with the navigational and traffic context of the ship. The probability that a platform will be hit by a drifting vessel is shown in Figure 6. The figure depicts the values for a drifting ship with an engine failure lasting one hour. As can be seen these probabilities are smaller than the probabilities for a high speed collision.

5. Conclusions

- The expected minimum recurrence period of a collision between a tanker and a platform at a high speed for all platforms on the North Sea is about 4 years. This value is a conservative one, since it is based on the current casualty records. This means that the real value of the NER might be significantly lower.
- The determination of this frequency is based on the casualty records, but a number of improvements in the calculation method can be made.
- The method as presented here should be extended with a more precise description of the effect of measures to reduce the frequency of impacts.

6. References


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Table 1
Figure 1
Number of platformyears in the North Sea
Number of passings of all platforms in the North Sea in 1987

- UK: 0
- NE: 600,000
- NO: 800,000
- DE: 1,000,000
- All: 12,000,000

Country of Continental Shelf
Maximum probability of a platform on a given Continental Shelf being hit by a passing vessel

Country of the Continental Shelf

- UK
- NE
- NO
- DE
- All
Relative average probability of a platform in the North Sea on a given Continental Shelf being hit

![Bar chart showing relative average probability for UK, NE, NO, and DE](image)

- **UK**: 3.18
- **NE**: 6.26
- **NO**: 1.00
- **DE**: 1.35

*Figure 5*
Figure 6

Probability of a platform involved in a drifting collision

Country of the Continental Shelf

- UK
- NE
- NO
- DE
- all

Probability:
- All ships
- Tankers
The calculation of both individual and group risk involves integration over a range of scenario characteristics, which can be viewed as random variables, such as released substance, release rate or amount, wind speed, wind direction, air stability and - in the case of line sources such as transport routes - accident location. So far, the most widely practiced method to carry out the calculation has been direct complete integration.

Although the use of Monte Carlo Simulation (MCS) has long since been acknowledged as a viable and often preferred solution to similar problems in the field of structural engineering, its application has, to the authors' knowledge, been rather limited in the field of hazardous material risk assessment.

The paper describes briefly the principles and mechanics of MCS in hazardous material risk assessment. It discusses the pros and cons of MCS and a more straightforward calculation method, both from a calculation engineering and a risk management point of view, to conclude that it all depends on .... what you use it for.

1. Classification of risk calculation problems

Many probability calculation problems take the following form. Let X denote a set of random variables, of which the joint probability distribution is known. Given the function G(X), what is the probability distribution of the random variable G?

From this general problem, which will be referred to as type 1 hereafter, two special cases can be drawn. Sometimes not the whole probability distribution of G may be required, but only P(G(X) ≤ g_0), the probability that G does not exceed a certain threshold value (type 2). In other applications the calculation of E(X), i.e. the expected value of G, suffices (type 3).
2. Quantitative risk assessment and risk management

In quantitative risk assessment, two measures are often used to express the risk level imposed by an activity on its surroundings: individual risk (IR) and societal risk or group risk (GR).

IR<sub>p,a</sub>, the individual risk on place p resulting from activity a, is defined as the probability of dying, due to an accident related to activity a, for a hypothetical average individual, residing constantly and unprotected on place p. Calculation of IR can be an aid in the risk management process, aimed at ensuring a sufficient level of individual safety for people living or working near sites where potentially dangerous activities take place.

GR<sub>a</sub>, the group risk resulting from activity a, is defined as the probability of exceedance of the number of fatalities due to an accident resulting from activity a. Calculation of GR can be a tool in serving another aim of risk management, which is to prevent accidents which cause large scale social disruption.

3. Principles of risk calculations

The core of both IR and GR calculation is the assessment of POD<sub>p|Z<sub>a</sub>,Y<sub>a</sub></sub>, the (conditional) probability of dying on place p, given an accident scenario resulting from activity a, that is characterized by a set of discrete random variables Z<sub>a</sub> and a set of continuous random variables Y<sub>a</sub>.

Individual risk is calculated, assuming that Z<sub>a</sub> and Y<sub>a</sub> are independent, as:

\[ IR_{p,a} = E (POD_{p|Z_a,Y_a}) = \sum_{Z_a} \int_{Y_a} POD_{p|Z_a,Y_a} P(Z_a)f(Y_a) \, dY_a \]  

(1)

and therefore by nature a type 3 problem in the framework mentioned above.

GR calculation requires the assessment of E(N<sub>f|Z<a>,Y<a></sub>), the expected number of fatalities, given an accident scenario resulting from activity a, that is characterized by a set of discrete random variables Z<sub>a</sub> and a set of continuous random variables Y<sub>a</sub>.

This expected number of fatalities is calculated as:

\[ E(N_f|Z_a,Y_a) = \int_{p} POD_{p|Z_a,Y_a} g(p) \, dp \]  

(2)

where g(p) is the population density on place p.
Writing $N_f$ as short for $E(N_f|Z_a, Y_a)$, group risk is expressed in terms of the complement of $N_f$'s cumulative distribution function:

$$1 - F(n_f) = \sum_{n_f = 1} \int P(Z_a) f(Y_a) dY_a$$

which is a type 1 problem.

Note:
This calculation procedure shows that the possible deviation of the number of fatalities from its expected value (given an accident scenario) is not taken into account, which means that in principle the variance of $N_f$ is underestimated. However, it should be borne in mind that the conditional probability of dying is meant as the fraction of a number of people, believed to die following the accident. This equals the probability of dying for one arbitrary person, but is not the probability that all of the group will die. If for the moment $p$ is the probability of dying over an area where $n$ people live, $n \cdot p$ is the expected number of deaths in the scenario and $\sqrt{(n \cdot p)}$ the standard deviation $(p<<1)$.

4. Calculation methods

As can be seen above, both IR and GR calculation involve integration over the whole or a part of the scenario variables space. These random variables are generally the nature of the released substance, release rate and duration, wind speed, wind direction, air stability, possibly water and air temperature and - in the case of line or area sources such as transport routes - accident location.

So far, the most widely practiced method to carry out the integration has been direct complete integration. Although the use of Monte Carlo Simulation (MCS) has long since been acknowledged as a viable and often preferred solution to similar problems in the field of structural engineering, its application has, to the authors' knowledge, been rather limited in the field of hazardous material risk assessment. In the framework of the Dutch "Safety of Inland Waterway Transport" project, MCS will be incorporated in a Risk and Effect Model, along with a more conventional calculation method.

5. Monte Carlo simulation.

Monte Carlo simulation is based on a repeating choice of a set of values for the random variables which are involved in the problem. The values are generated by using a random number generator, yielding a uniformly distributed number between 0 and 1, and the inverse distribution functions for the variables.
The function $G(X)$ is evaluated for each set of values. The probability $P(G(X) < g_0)$ (type 2 problem) is estimated as:

$$P(G(X) \leq g_0) = \frac{N(G(X) \leq g_0)}{N_t}$$ (4)

where $N(G(X) \leq g_0)$ is the number of simulations for which $G(X) < g_0$ and $N_t$ the total number of simulations.

The number of simulations in a MCS is related to the reliability and the probability level of the result.

If $P$ is the actual probability and $P_c$ is the calculated probability, the relative error ($e$) is calculated as:

$$e = \frac{(P - P_c)}{P}$$ (5)

The mean error, $\mu(e)$, and the standard deviation of the error, $\sigma(e)$, are as follows:

$$\mu(e) = 0$$ (6)
$$\sigma(e) = \sqrt{\frac{P_c(1-P_c)}{N}}$$ (7)

The error ($e$) is normally distributed. If $E$ is the target relative error, with a two-sided confidence level $\alpha$, this corresponds to a value $k$ in the standard normal distribution:

$$k = E / \sigma(e)$$ (8)

$$\Phi(-k) = \alpha/2$$ (9)

where $\Phi$ is the cumulative distribution function for the standard normal distribution.

So the required number of simulations is calculated as:

$$N = \left(\frac{k}{E}\right)^2 \left(\frac{1 - P_c}{P_c}\right)$$ (10)

and depends on the target relative error ($E$), the target confidence level (represented by $k$) and the probability level of interest ($P_c$).
To calculate IR at a certain place (p) the function \( G(X) \) is \( \text{POD}_p(Z', Y) \), where \( Z' \) and \( Y \) are sets of random variables.

Basically, MCS is a method for continuous random variables. As mentioned above, the scenarios used to calculate the probability of dying are partly characterised by a set of continuous random variables \( Y \) and partly by a set of discrete random variables \( Z \). For the MCS method, the latter has to be transformed to a set of continuous random variables \( Z' \). Let \( z \) be a discrete random variable with two possible values, true and false, each with a certain probability. In the MCS a random number between 0 and 1 has to make the choice between true and false. Comparing the probability \( P(z = \text{false}) \) with the random number \( (z') \) will make the choice:

- if \( P(z=\text{false}) \geq z' \) then \( z=\text{false} \),
- if \( P(z=\text{false}) < z' \) then \( z=\text{true} \).

The same concept is used when \( z \) is a discrete random variable with more than two possible values.

Given \( N_t \) simulations the individual risk is calculated as:

\[
IR_p = \sum_{i=1}^{N_t} \frac{\text{POD}_p(Z'_i, Y_i)}{N_t} \tag{11}
\]

POD is the probability of dying on a certain place. The value of the probability of dying is between 0 and 1. The convergence of \( IR_p \) with a growing number of simulations depends on the variance of \( \text{POD}_p \). The most unfavourable case occurs when \( \text{POD}_p \) is either 0 or 1.

Let \( \text{POD}' \) be a function with only two values: 0 and 1, meaning alive and dead. Let \( N_d \) be the number of simulations that \( \text{POD}' \) is 1. The individual risk is then calculated as:

\[
IR = \frac{N_d}{N_t} \tag{12}
\]

Now the calculation of the individual risk can be seen as a type 2 problem (cf. eq. 4) and the assessment of the number of simulations required for a certain reliability and a certain probability level is as above (cf. eq. 10).

The calculation of the group risk is, as mentioned above, a type 1 problem. Each simulation results in an expected value of the number of fatalities \( (N_f) \), given the (random chosen) circumstances. The probability function can be calculated by dividing the number of simulations...
with more than \( N_f \) fatalities by the total number of simulations, for all values of \( N_f \).

\[
P(N_f > n_f) = \frac{N(N_f > n_f)}{N_t} \quad (13)
\]

The number of simulations depends on the choice of the minimum required probability level, again according to eq. 10.

6. Direct complete integration.

The direct complete integration is based on a numerical solution of the integral mentioned above. The range of continuous random variables is replaced by sets of discrete values. For each set of values the function \( G(X) \) has to be calculated. The probability \( P(G(X) < g_0) \) (type 2 problem) is calculated as:

\[
P(G(X) < g_0) = \sum \sum \cdots \sum P(x_1, x_2, \ldots, x_n) \quad (14)
\]

If the range of each variable is represented by a set of \( N_v \) discrete values and there are \( N_r \) random variables involved in the problem, the number of simulations \( N_t \) is:

\[
N_t = N_v^{N_r} \quad (15)
\]

Therefore, the total number of simulations depends on the number of random variables involved and the number of discrete values that is evaluated for each variable. The reliability of the results depends on \( N_v \), the number of discrete values that is evaluated for each variable. To estimate the relative error, successive calculations with increasing numbers of discrete values have to be made, until the result stabilizes.

The individual risk at place \( p \) is calculated as:

\[
IR_p = \sum \sum \cdots \sum POD_p(Z, Y') P(Z, Y') \quad (16)
\]

where \( Z \) is a set of discrete random variables and \( Y' \) a set of the discretized, originally continuous, random variables.
If $POD'$ is a function with only two values, 0 and 1, the individual risk is calculated as:

$$IR_P = \sum_{POD(Z, Y')} \ldots \sum_{1} P(Z, Y')$$ \hspace{1cm} (17)

So again the problem is like a type 2 problem.

The group risk is calculated in the same way. The total distribution is needed, so at different levels of the number of fatalities $N_f$, the probability of exceeding this number is calculated:

$$P(N_f > n_f) = \sum_{n_f} \ldots \sum_{N_f} P(Z, Y')$$ \hspace{1cm} (18)

7. Comparison

As is shown above, for both methods the accuracy of the result gets better with a growing number of G-function evaluations, i.e. calculations of the probabilities of dying over the total area where adverse effects occur. Clearly, calculation time also increases with a growing number of G-function evaluations. Therefore, there is always a trade-off between calculation time and accuracy. For this reason, the performance of both methods should be compared in terms of calculation time for the same accuracy, or alternatively in terms of accuracy for the same calculation time.

The number of simulations with Monte Carlo simulation is:

$$N_c = \frac{C}{P}$$ \hspace{1cm} (19)

where $C$, given the desired level of accuracy, is a constant and $P$ the probability level of interest.

With the direct complete integral, the number is:

$$N_c = N_v^{N_f}$$ \hspace{1cm} (15)

So with small probabilities the Monte Carlo simulation is not a quick method, but the speed is independent of the number of random variables. The direct integral cannot be used with too much random variables and the reliability is not explicitly known.
If the required number of discrete values for each variable, $N_v$, for a sufficiently accurate result, is known, the critical number of random variables $N_{r,c}$ is calculated as:

$$N_{r,c} = \frac{\log C - \log P}{\log N_v}$$

(20)

Example: let both methods be equally accurate with $C=100$, $P=10^{-6}$ and $N_v=20$. The critical number of random variables in this case is $N_{r,c} = 6.2$. So with 6 (or less) random variables for this problem the direct complete integral is the fastest method, for more than 6 random variables the Monte Carlo simulation is more effective.

Besides this speed/accuracy trade-off, the methods differ with respect to two other aspects.

With the method of the direct integral the exact sets of values of all simulations that will be made are known before the calculation is started. With the MCS the number of simulations is known, but the set of values of the random variables is generated only just before each individual simulation. So the function $G(X)$ has to be a function that can handle all possible combinations of values. With safety problems, especially safety problems of transportation, many possible scenarios are calculated, using various models. So the function $G(X)$ is not a smooth function and problems can occur.

With the direct integral method the result of every calculation with the same situation will be exactly the same. With MCS the result of calculations with the same situation will be slightly different (unless the same seed for the random generator is used).

8. The choice

Making a choice between the two methods is in general not too difficult. It is a choice depending on the problem. When the number of random variables is small ($\leq 4$), the direct integration will be more effective, especially when interest is focussed on small probabilities. When the number of random variables is about ten or more an accurate result with the direct integral method will take a long time, so MCS is more effective.

The problem of the GR and the IR is critical. Both methods will take a lot of time. The probability level of interest is extremely small and the number of random variables is not small. At this moment the direct integral is commonly used. In the future more knowledge of the random variables, the assessment of POD, etc. will be available. So a more accurate result of the risk calculations will be required, which means more random variables and more discrete values for each random variable for which the $G$-function has to be evaluated. With the direct integral
method, because of calculation time, the implementation of enhanced knowledge is hampered. MCS could be the solution.

But making a choice between MCS and direct integration is not only a technical matter. An agreement on how to calculate the risk is essential in order to ensure that decisions, based on the risk assessment, are accepted. In this respect it is very important to make sure that every calculation of the same situation will produce exactly the same results. The possibility, that occurs with MCS, that the outputs of two risk calculations with exactly the same input differ, one just above and the other just below the critical level, could be a disaster in risk management.

If the method of risk assessment is agreed upon by all parties involved - not at least the party that may "suffer" from the results - the question whether or not the calculation is correct or accurate, may be of less importance. However, consensus will be more readily reached if reality is modelled as closely as possible.
MANAGEMENT AND RISK ASSESSMENT
NAUTICAL SAFETY AND EFFICIENCY:
SIMULATION AND REALITY

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ABSTRACT

The paper deals with training and research using maritime simulation techniques to provide cost-effective and safe solutions to maritime transportation problems. In order to reduce the probability of accidents, training and research is required in which the human factors are fully taken into account.

1. INTRODUCTION

The investigation of marine casualties has concentrated so far mainly on technical malfunctions, ignoring the human factors. However, these human factors are in the majority of cases the main cause of the casualties. In addition, in most cases, there is not one single factor, but a combination of factors which makes every accident or incident a unique case. A famous example is the accident with the TORREY CANYON which ran aground in the Scilly Isles in March 1967 and spilled all her oil, causing colossal pollution. Below follows a quote from the Board of Investigation (ref. 1):

'The Master was negligent in the following respects:
He took the ship between the Seven Stones and the Scillies, rather than between the Seven Stones and Land's End. Despite the presence of fishing vessels and nets, he kept the ship on automatic steering, failing to put her in hand steering.
He failed to reduce speed at any time prior to the stranding and especially at 08.40 when he reckoned he was nearer to the Seven Stones than he had previously thought and when a turn to 325° was prevented by the presence of a fishing vessel on his port side.
He had not established any regular or routine practice for the operation of the steering wheel selection lever.'

In addition the Master (Captain Rugiati) had not taken into account the strong current, so the report goes on:

'It is interesting to note that Capt Rugiati was not the only seafarer to be deceived by the strong northeasterly set which put the TORREY CANYON further to the north and east than he expected. The strong set is a well known phenomenon at certain times of the year. It runs between Ushant and the Scillies and has accounted for many of the 257 known wrecks on the troublesome rocks and islands of the Scillies.'

'The TORREY CANYON had good visibility, modern navigational aids, daylight radar and there was no gale. Small wonder that the Board of Investigation found that only human error was to blame.'

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This is one of the many examples in which human error can be isolated as the main cause of a major marine casualty. Another more recent example is the stranding of the 125,000 M\textsuperscript{3} LNG Carrier 'EL PASO PAUL KAYSER', which stranded on a pinnacle of the La Perla Shoal in the Strait of Gibraltar on 29 June 1979. After a careful analysis it was concluded that the following lessons could be learned (ref. 2):

1. The preparation and execution of a passage plan is essential for safe navigation.
2. Adequate numbers of men on the bridge do not make an adequate bridge organisation. The bridge team must actively support the conning officer.
3. Total reliance on a CAS radar can place a vessel at great risk.

The list of "famous" accidents in which human factors and human errors play a dominant role can be extended with accidents as those with the EXXON VALDEZ and the HARALD OF FREE ENTERPRISE.

In order to reduce the probability of such accidents research and training is required. This is the area in which the Maritime Simulation Centre Netherlands (MSCN) is active. In the following chapters an overview is provided of activities in the areas of training and research with respect to nautical safety and efficiency.

2. TRAINING

2.1 Introduction

From incidents like the above mentioned, it can be concluded that communication and coordination in a bridge team is very important. Every member of the team has to know his tasks and responsibilities within the procedures for the various situations. Due to all kinds of reasons procedures are not always executed as they should. Training of bridge teams in the execution of the procedures can help to reduce the risks of loss of equipment, cargo (environmental dangers) and of course people.

Nowadays, more demands are made upon the flexibility, skills and knowledge of the bridge crews and pilots. Some of the reasons are:

- the tendency to reduce the size of the bridge crews;
- the increasing number of tasks on the bridge (apart from navigation and communication also engine room monitoring and cargo handling);
- the decrease of operational time on board (less practice);
- the increasing emphasis on safety in relation to risk of environmental pollution;
- the fact that about 80\% of the accidents at sea are due to human error;
- the increasing use of high technology equipment / automation on the bridge;
- the increasing need of flexibility of ship crews and pilots in view of different levels and/or standards of automation and different types of equipment;
- the differences in procedures for different types of ships;
- the increasing number of "mixed" bridge crews with respect to culture and level of education;

To attain optimal functioning of the bridge crews and pilots, simulation of various situations significantly contributes to the improvement of performance. However, in the field of full mission bridge simulators, the structured development of training is way behind the technical developments
in that area. Therefore a structured approach to the development of training programs for the shipping industry and education is needed.

2.2 A structured approach to training development

The first step in the development of a sound training program is a thorough task, skills and knowledge analysis. The information gathered in these analyses, resulting in detailed learning objectives, form the basis on which further training development must take place.

The next steps in the development process are concerned with the development of the training scenarios and other training materials. All of the above mentioned must result in framework like basis training modules (see figure 1).

![Training Module Diagram]

Figure 1: A training module

From this figure can be seen that the starting point for a basis training module consists of an established basis of the analyzed tasks, skills and knowledge and the resulting learning objectives.

At this moment, MSCN is developing basis modules for three types of technical simulator training programs:
- **procedure training** to practise bridge procedures which should be executed in various dangerous and/or critical situations;
- **skill training** which is aiming at specific skills like the docking of a ferry in difficult circumstances or piloting skills;
- **familiarisation training** to get the pilot or bridge officer used to the behaviour of a new type of ship and/or modified ports and freeways.

These basis modules again, form the starting point for the development of tailor made training programs, based on the specific needs and wishes of the customer. In this way quick and effective custom made training development can be realised.
2.3 Non-technical Training

The Bridge Crew Management Training course of MSCN has originally been developed by the Royal Dutch Airlines (KLM) to improve the non technical skills of the cockpit crew. The course has been adapted for application in the nautical world by MSCN.

The objective of the BCMT are promotion of team spirit and improvement of communication to create an effective and reliable organisation with an optimal problem solving ability on board ships.

In the training course the following skills are trained:

Communication
Communication forms the basis for the effectiveness of an organisation, the correctness of decisions and a good cooperation. During the course, attention will be paid to different styles of communication and their effects.

Motivating people
How can others be influenced positively? Due to the training course one becomes more aware of the effects that certain actions and communication (styles) have on work motivation.

Rational Decision-making
Taking and monitoring decisions is a complex process, in which many potential pitfalls are hidden. In rational decision making a 7 step method for Rational Decision-making is used in which attention is dedicated to fact finding, distinguishing facts from assumptions, judgements and prejudice.

Thinking under pressure
What happens to human information processing under (time)pressure? If one is aware of the effects which (time)pressure has on human information processing, one can take this into account, so that the ultimate quality of decisions increases.

Speaking up
In preventing wrong decisions it is important that decisions and the decision making processes are monitored by more than one person. If a lower rank notes serious mistakes in the execution of tasks on board, then he has to inform his superior. Also if the superior has initiated the wrong decision or procedure.

Cultural, political and group differences
Working and team-building with people from different cultures makes high demands on the communication skills of the crew. Miscommunication and misunderstandings can easily lead to irritations. The same applies to group differences based on differences in education. How to deal with these situations is an important part of the training.

Stress management
How can stress symptoms be recognized? When is stress harmful and when is it useful? How can stress be controlled and how can the resistance to stress due to working conditions be increased? These and related questions will be treated in depth during the training course.

2.4 The Training Evaluation System (TES).

Since the early days of maritime simulation a lot of time has been devoted to the training of pilots and bridge officers in different tasks. Although nobody shall deny that actual learning took place during the simulation sessions there is (in most cases) no clear proof of this learning process. This,
despite the fact that a lot of money has to be paid to the owner of the simulator facilities for use of the equipment and the activities of the instructor.

For that reason MSCN has started with the design and development of a Training Evaluation System (TES, see figure 1) which will be designed for the following reasons:

- to obtain information on the quality of the different elements in the training process
- to optimize the overall quality of the training programs. TES will be part of the NEN ISO 9001 quality assurance procedures within the training department of MSCN;
- to monitor the performance of the trainee to optimize the individual training course.
- to provide the client with information on the effectiveness (value) of the training program;

TES is integrated into the training design procedure which describes the development process of all the (simulator) training courses at MSCN. This means that TES covers the whole range from the first contact with the customer until the measuring of the transfer of the training after the execution of the training. In this way TES can also easily be integrated into the NEN ISO 9001 quality assurance procedures for training design and execution.

Within TES, four types of informants are used to obtain the needed information about the training:
- The customer;
- The MSCN training experts;
- The instructor;
- The trainees.

The customer is asked to describe his training needs as good as possible. These needs are translated by MSCN into the training profile which is the training blueprint. After the execution of the training, the customer is asked to monitor the performance of the trainees who received the training in order to determine the transfer of the knowledge and skills from the training to the daily work routine.

The MSCN training experts are conducting and monitoring the training design process and the execution of the training. They check whether the customer's needs are correctly translated into the training profile and again if the training profile is correctly translated into the training products. During the execution of the training, they observe some training sessions to note whether the training is executed according to the plan.

The MSCN expert uses one of the most important instruments of TES: the instrument to measure skill and knowledge improvement. On this moment (October 1992), this instrument is in a premature phase but the current design tells that the instrument will combine objective and subjective measures to be able to determine skill and/or knowledge improvement.

The Instructor is asked to give his opinion on the training: for example the objectives, the materials, the time schedule and the content. He is asked if there were any troubles during the training and what the causes were according to his opinion. Also, he gives his opinion on the skill and knowledge improvement of the trainees.

The trainees are asked to give their opinion on the training: for example the objectives, the course materials, the instructor, the simulator and the time schedule. Also they are asked if they think that their skills and knowledge is improved during the training.
3. NAUTICAL RESEARCH

Many designs and operational problems require a thorough analysis of these problems using appropriate research tools.

Two research approaches can be distinguished to obtain a better understanding of the often complex nautical process.

The first approach is based on data analysis techniques. This involves data reduction to obtain derived measures (e.g., for risk of safety) or extrapolation, generalisation or prediction of new situations (often in statistical terms).

The second approach is based on simulation of the complex process. This allows a systematic investigation of the effect of the many variables such as ship dynamics, environmental variables, navigational aids, human factors, regulations, etc. Especially human factors can play a crucial role in the safety and efficiency of ship handling.

3.1 Real-time simulation

These 'man-in-the-loop' problems can be studied utilizing real-time simulators with real human beings. This represents the reality to a very high degree especially as far as the human factors, his capabilities and limitations are concerned. This includes the variability due to differences in the skills of pilots and shipmasters (see before about training).

Ship handling simulators consist of a bridge with bridge instruments and controls, an outside view and driven by a mathematical model of ship motions. MSCN capability consists of two full mission bridge simulators, including manoeuvring, engine room and cargo handling. In addition a Vessel Traffic Simulator (VTS) is available at MSCN, which can be linked to the full mission manoeuvring simulators.

Although a simulator is a sophisticated tool to provide reliable answers to nautical safety and efficiency questions, its use can be relatively costly due to the vast number of conditions to be tested and the large number of test runs to be performed for each condition in order to arrive at a reliable answer.

Therefore MSCN utilizes also fast-time simulation models, in which the role of the human operator(s) is described in mathematical terms. Especially early in the design stage, models can be used to analyze systematically all relevant factors of the complex process and to select design alternatives. This is discussed in the next section.

3.2. Fast-time simulation models

In this section the fast-time simulation models developed and/or used by MSCN are reviewed. The starting point of all models is that a planned route has to be realized, in terms of a given (number of) track(s). The models vary from a simple autopilot to a detailed description of the total navigator-ship system including explicitly human functions, such as visual perception, information processing, decisions making, planning and controlling. In addition simple ship operations are considered, as well as ship assistance by tug boats, and the total vessel traffic process.

3.2.1. SHIPMA model

The SHIPMA model (Ref. 1) is basically an autopilot based on conventional servo-system principles. It comprises several control modes (track keeping, zig-zag manoeuvring, making a turning circle and a tug control mode). In this paper only the (normal) track keeping mode will be discussed.
The autopilot is designed to follow a user-specified reference track (in terms of waypoints and radii of bend for the track transitions) as well as possible. The rudder angle is basically determined from the following relationship

\[ \delta = C_{\Delta r} \Delta r + C_{\Delta \Psi} \Delta \Psi + C_{\Delta y} \Delta y \]  

(3.1)

where \( \Delta r, \Delta \Psi \) and \( \Delta y \) are deviations from a reference point on the track a given (to be specified) distance ahead. This way adaptive (i.e. track independent) dynamic response is obtained at the cost of computational effort to generate \( \Delta r, \Delta \Psi \) and \( \Delta y \). However, some trial and error might be required, for a specific case, to modify the nominal feedback gains.

3.2.2. FORCESIM model

The FORCESIM model (Ref. 2) can be used to compute optimal control settings, such as rudder angle and RPM and an optimal use of manoeuvring devices such as tug boats (tug boats are simply represented as force vectors), for executing a prescribed manoeuvre for a given vessel and environment. Also this model does not include the navigators with their variable behaviour. The (deterministic) model indicates the upper boundary of the ship manoeuvring capability and shows if a desired manoeuvre could possibly be realized.

The model includes a nonlinear, time-varying mathematical model of the ship dynamics, including the effects, of the control variables (rudder, RPM, tug forces, etc.) and of environmental disturbances such as wind, current, waves and bottom and bank effects.

This can be represented by

\[ x(h) = f(X(k-1), U(k-1), W(k-1), h) \]  

(3.2)

where \( X(k) \) is the state vector (consisting of position, speed, heading etc.) at time \( k \), \( f \) is a vector function, \( U \) is the control vector and \( W \) is the disturbance vector.

The task to be executed is sailing from A to B, possibly with pre-described intermediate positions, heading, speed, etc. This tracking task can be expressed as

\[ J_N(U) = E \left[ \sum_{k=1}^{N} (X(\ell) - X_d(\ell))/Q_x(\ell) X(\ell) - X_d(\ell) + U'(\ell-1)/Q_u(\ell-1) U(\ell-1) \right] \]  

(3.3)

where \( J_n \) is the resulting performance measure corresponding with a given interval of time \([0, N]\) which will be minimized by the optimal control \( U \), \( X_d \) indicates the desired state trajectory and \( Q_x \) and \( Q_u \) are weightings.

The approach is formulated in terms of Pontryagin’s maximum principle. Numerically, the procedure is based on the conjugate gradient method.

In general FORCESIM can be used to

* determining the manoeuvring devices needed for the execution of a manoeuvre under various environmental conditions for various vessels;
select critical situating and interesting conditions to be investigated, for example in real-time simulations;
* develop manoeuvring strategies.

3.2.3. **TUGSIM model**

While in FORCESIM tug boats are simply represented as force vectors the TUGSIM model (Ref. 3) explicitly deals with the manoeuvring with tug boats. So the model describes for a given ship to be assisted (with given speed and course) and for given commands of the ship pilot, in terms of tug force (percentage of power) and direction, how the tug boat captain is executing dynamics, the environment (current, wind) and the manoeuvring strategy.

Basically the modelling approach of TUGSIM, which is being developed at MSCN, is the following. Several tug models (direct pulling), stand-by etc. corresponding with specific tug commands of the pilot and boundary conditions of the tug power, cable direction and tug boat controls (thrust and direction or rudder angle).

The model determines how each tug mode can be realised (stabilised) by the appropriate tug boat control. Basically, the model determines the most efficient tug boat control, corresponding with the maximum cable force, given the ship dynamics and other constraints.

In addition it is described how the tug boat is manoeuvring to change from one mode to another.

It may be expected that this leads to realistic tug boat behaviour and a useful simulation tool, although in reality the interaction between pilots and tug boat captains can be somewhat more complicated depending on the extent to which tug boat captains anticipate and take own initiatives.

For the time being, only the control behaviour is modelled, assuming that the uncertainty of assessing the situation is of minor importance. Thus basically, the present modelling effort is aimed at the design of an autopilot.

3.2.4. **NAVSIM model**

The NAVSIM model (refs. 4 and 6) is based on the fundamental hypothesis that the human operator (HO) behaves optimally subject to his inherent limitations and constraints ("he does the best he can"). The result is both a normative model, starting from task objectives, and a descriptive model, including realistically HO functions and actions.

NAVSIM provides a sufficiently detailed framework to describe systematically the complex interaction between the HO functioning and his task environment. The model components are:

* ship dynamics and environmental variables as given by e.g. (3.2); the information that is available of the system from instruments and the outside world is given by the output vector \( Y \), functionally related to the state and controls according to

\[
Y (k) = g (X (k), U (k), k)
\]  

(3.4)

* task definition as expressed by e.g. (3.3);

* HO functioning in terms of perception, information processing, decision making, planning and controlling;

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model outputs in terms of statistical measures of system performance (providing all statistical information of the process) and HO workload measures.

Perception of the present state and the future desired state (by looking forward) is associated with an inaccuracy (observation noise) which can be related to perceptual thresholds and the level and allocation of attention.

The information perceived by the HO is used to estimate both the present state and the future desired state of the ship. This estimation process is modelled in terms of a Kalman filter.

Based on the estimation process the sequential decision is made whether systematic changes in the desired state occur. This means that if, for instance, a turn must be executed this is envisaged in time so that the proper actions can be planned and executed.

Once this decision is made, a pre-programmed manoeuvre is planned and executed to achieve the desired future state. In addition, deviations from the present desired state are compensated by means of a closed loop control to account for random effects.

The NAVSIM model can be applied in port and fairway design, risk analysis, the evaluation of navigational aids and workload studies.

3.2.5. TRASIM model

The TRASIM model describes the total vessel traffic control process. This implies a number of ships, with a given planned route, in a given confined area. The navigation of each ship is based on a planned route, which is updated via information of the visual scene, instruments and the vessel traffic services (VTS). Both normal operation and collision avoidance is modelled. The later implies the detection of a possible conflict by the navigator(s) and/or the VTS. Both the collision situations and the standard avoidance manoeuvres are strongly determined by procedures and rules.

The ultimate criteria of the traffic process are safety and economy. Derived measures for these are collision risks (probabilities) and traffic flows. These are related to the following aspects, which are included in the model: ship dynamics, on board navigation instruments, visibility and environmental conditions, navigation aids, number of ships and their planned route, HO and VTS functioning. This involves visual perception, information processing, decision making and control (similar as in the NAVSIM model). The result is a stochastic, nonlinear, estimation and control problem.

Normal operation amounts to steering the ship along the planned route (LQG control). The nonlinear dynamics of the (N) ships are modeled in a simplified form, assuming no drift, yet describing the main response characteristics, realistically.

Based on perceived information the navigator estimates his own ship related state \( X_i \) and the state of other neighbouring ships \( X_j \) and the variables that are involved in the collision avoidance process \( X_{ij} \). The latter variables describe the interaction between ships and are given by

\[
X_{ij} (k) = f_i (X_i (k), X_j (k))
\]

These nonlinear relationships imply a non-Gaussian probability distribution of \( X_{ij} \). Instead of trying to find approximated filter equations based on the conditional probability distribution, in the model stochastic differential equations are derived for \( X_{ij} \) to obtain a minimum variance estimate of \( X_{ij} \) in terms of an extended Kalman filter. This is the same approach as taken for the estimation of the other ship states \( X_i \).
Collision avoidance is modeled by defining a dangerous encounter if the (estimated values of the) following three variables are smaller than their corresponding criterion value: the distance \( a_{ij} \) between two ships, the closest point of approach \( c_{ij} \) (defined as the distance between the relative velocity vector and ship \( i \)) and the time \( T_{ij} \) to reach the closest point of approach. This is clarified in Fig. 2.

Thus

\[
X_{ij} = \text{col} \{ a_{ij}, c_{ij}, l_{ij} \} \quad (3.6)
\]

So we have an encounter if all element of \( X_{ij} \) are smaller than the corresponding elements of the criterion \( X_{cij} \). However, because \( X_{ij} \) is a stochastic process the navigator uses an estimate of \( X_{ij} \) (\( X_{ij} \)). If all elements of \( X_{ij} \) are smaller than their corresponding criterion values the decision (D.) is made that a collision avoidance situation is apparent followed by an action if ship \( i \) is burdened.

Thus

\[
\bigwedge_{D_i} X_{ij} > X_{cij} \quad (3.7)
\]

Three types of encounters are distinguished each requiring a specific, pre-programmed, avoidance action: meetings, overtakings and crossings. The precise classification is depending on the relative positions and orientations of both ships.
The evasive manoeuvre is characterised by a given lateral displacement and a given heading change. This standard manoeuvre is uniquely realized by a bang-bang control sequence with a given maximum rudder angle.

Various ways to model the VTS are possible. The simplest way is to assume that the navigator receives given (extra) observations from the VTS. A more advanced role of the VTS can be modeled assuming that the VTS will have information to estimate the total vessel traffic process, detect any conflict and advise or command the navigators (based on the same model concept as used for the navigators).

The vessel traffic model is nonlinear because of the nonlinear equations of motion and the nonlinear estimation process. Therefore, no closed form expressions can be derived for statistical measures, such as collision probabilities. Thus the model must be used for time (Monte Carlo) simulations. For example, for typical (crucial or interesting) configurations time simulations can be made. The resulting trajectories can be considered and combined to obtain measures for collision probabilities and traffic flows. In addition, measures will be available for the effect of visual informational variables, or the effect of rules and procedures, on system performance and measures of navigator behaviour related to visual scanning, situation uncertainty and workload.

The model can be applied to a variety of vessel traffic problems. It provides the structure to analyze the effect on safety and traffic handling of (among others) the following variables: ship dynamics, on-board navigation instruments, visibility and environmental conditions, aids to navigation, navigator functioning, number of ships and routes in the traffic area, procedures and rules, role of the VTS, etc.

4. MODEL EVALUATION AND VALIDATION

In evaluating the use of simulation techniques in general, and of the foregoing models specifically, the starting point is which questions have to be answered, or which problems have to be solved. If these are related to human operator functions, such as perception and information processing of visual aids to navigation, of outside world cues and of instruments, then the NAVSIM model is required to simulate the corresponding tasks appropriately. If the questions are related to more complex manoeuvres than just track keeping with a constant forward speed, such as (un)berthing, mooring and turning, requiring tug boat manoeuvring in all possible directions, then the FORCESIM or TUGSIM model should be utilized. In addition, in case more advanced hydrodynamic ship models (than the Abkowitz model involved in SHIPMA) and more elaborate models of the environment and of the disturbances are required then a real-time simulator or the NAVSIM model, FORCESIM model or TUGSIM model should be used. In case it is not justified to assume that the deterministic disturbances are exactly known, the NAVSIM model is required to simulate such situations. In that case the disturbances (e.g. current) have to be estimated based on inaccurate measurements or other observations.

The SHIPMA model can be used to get a first impression of manoeuvre capability. In case the ship dynamics and the environment are adequately modelled, SHIPMA can provide an upper bound on manoeuvring capability, i.e. if performance with SHIPMA is unacceptable the task has to be redesigned because in reality the performance will be equal or worse (because of human operator effects, etc.). However, in case the SHIPMA performance is acceptable, a more realistic simulation, is mandatory using NAVSIM or a real-time simulator.
Validating complex simulation tools is the most important but also the most difficult issue: what is the meaning of the simulation results. Practically, it makes sense to show that the results are useful (to answer questions, etc.). The standard procedure for doing this is to analyze certain control tasks and to predict with the model system performance and other measures, which can also be measured in an (e.g. simulator) experiment. A certain agreement between model prediction and experimental results builds up some confidence one has in the model. Validating a real-time simulator is more difficult. A careful comparison with real-life experiments is difficult to perform. Typically a simulator is validated by checking simulator components and based on subjective opinion.

Of the aforementioned models only the NAVSIM model results are supported by corresponding experimental results of 2 simulation programs (Ref. 7). In addition, parts of the model have been supported extensively in previous studies (Ref. 6). The SHIPMA model and the FORCESIM model are face validated, i.e. the results of several studies have been confirmed by nautical experts to be reasonable. The TRASIM and TUGSIM models have not been validated yet.

5. CONCLUDING REMARKS

In this paper training and research tools are reviewed to simulate ship handling.

Real-time simulation with a real human being in the control loop comes closest to reality. It is a dynamic process in which the human factors, his possibilities and his shortcomings are fully taken into account. This includes the variability due to natural differences in the skills of pilots and ship masters. A real-time simulator is a standard tool for training purposes.

One step further down the validity scale one finds man-machine models in which the ship dynamics and human functions are modeled. The models vary in the sense the different aspects of the manoeuvring task are modeled.

The SHIPMA model is basically an autopilot to provide an upper bound on manoeuvring capability. The FORCESIM model describes more complex manoeuvring tasks utilizing tug boats. If tug boat manoeuvring per se is involved, the more advanced TUGSIM model should be used. The NAVSIM model deals extensively with human operator aspects of single ship operations. The TRASIM model involves human operator functions in the context of the complex vessel traffic process. Apart from normal ship operation (track keeping) this involves the interaction between ships (collision avoidance) and communication between ships and the vessel traffic services.
6. REFERENCES


Abstract

One of the tasks of the Rotterdam Municipal Port Management is to ensure safety and expediency of shipping. To this end a safety study is being carried out with the following aim: to develop an optimal traffic handling system, i.e. a system enabling an efficient traffic flow, whilst maintaining an accepted safety standard using the facilities in an optimal way. Safety and efficiency are strongly interrelated. The most suitable method to compare and evaluate safety and efficiency is to express these quantities in monetary units. In this way also insight can be gained into the economical aspects of safety and efficiency.

The paper presents some results of this study "Safety as a product" and focuses on the parts set-up to provide an overview of all cost aspects in safety evaluation. Attention will be paid to the methodology of the study and results will presented for cost components with respect to nautical safety and efficiency of shipping. The main cost factors will be determined and ways will be sketched to reduce their impact.

1. Shipping policy of the Rotterdam Municipal Port Management

One of the key functions of the Rotterdam Municipal Port Management consists of providing nautical services. The main objective is: supporting the economical process by realisation of an efficient navigation in the port, under the conditions of a sufficient safety level and limited environmental effects. This objective is strived after by operating an optimized nautical infrastructure and by means of an effective information process.

Safety is usually considered in terms of risk and thus as unsafety. Unsafety is counter-productive. Incidents result in obstructions in the logistic chain. From this follows that reducing unsafety prevents the loss of money due to damage or delay. This is a conclusion
somewhat different from the view of permanently reducing risk. Below a certain level of risk - in terms of probability of an accident - it is not useful to decrease this probability even further. This also implies that an economic approach is useful. Following our main device it is clear that safety is no goal in itself but has to be evaluated together with other interests. This implies that a certain degree of risk has to be accepted. The key question is: which level of risk is acceptable. The appropriate framework for answering this question should be found in a safety policy.

In accordance with the overall objective of the Rotterdam Municipal Port Management (promoting activity in the port and the industry), three safety objectives have been defined:
- internal safety: to maintain a sufficient level of safety within the port;
- external safety: to maintain an acceptable level of risk to the public outside the port area;
- long-term safety: to maintain such a water quality in the port that sludge can be dredged without any restrictions.

Looking into more detail, this results into the following objectives: prevention of accidents within the port and limitation of the effects should accidents occur. Considering accidents the following categorization proves to be useful:
- "daily" accidents, characterized by a high frequency and small effects;
- large scale accidents, characterized by a low frequency and major effects;
- catastrophies, characterized by a very low frequency and enormous effects.

These accident categories have their own prime instruments in the overall policy: for "daily" accidents physical planning is the main instrument, as prevention is rather difficult. Large scale accidents should be prevented as much as possible and the effects should be limited. The prime instrument is an adequate incident fighting organisation and equipment. At last catastrophies should be prevented. Obviously the three types of accident do have an interdependency. Prevention for one type will have its beneficial effects on the other types, the instruments to limit the effects do work throughout the chain.

2. Safety and efficiency in shipping traffic

2.1 Introduction

It is realised internationally, that nautical safety cannot be separated from efficiency of
navigation. Measures taken to enhance safety can at the same time reduce or enlarge the efficiency of shipping traffic. So, next to safety the efficiency will have to be addressed in a safety policy.

There are various parameters influencing safety and efficiency of navigation. Apart from regulations and infrastructure several nautical services can be mentioned: pilotage, VTS (Vessel Traffic Service), patrol vessels, tugs, aids to navigation etc. Most of these safety means are privately operated; the VTS and patrol vessels are under the competence of the port authority.

Because the port management has various - partly overlapping - nautical services at its disposal, it is necessary to determine which combination of means under a prevailing safety standard makes the nautical key function available in the most efficient way.

Safety is usually expressed as risk, in probabilities of accidents and the size of their effects. However, it is often unknown which level of risk is acceptable. In our opinion it is perhaps more uniform to express nautical safety or unsafety in damage or the financial consequences of an accident - i.e. immediate damage to ship or infrastructure as well as consequential damage due to the blocking of shipping traffic and environmental effects.

Doing so it will be possible to evaluate the efficiency of the various nautical safety systems by analyzing costs versus profits.

2.2 Set-up of safety study

In the safety study the following four phases can be distinguished:
1. data collection with respect to ship movements, nautical accidents, hydro-meteo parameters, nautical efficiency and cost
2. data analysis
3. strategy development
4. implementation

The first two phases have ended now. Much effort has been put into collection and analysis of data. It was concluded that a regular evaluation of safety and efficiency of navigation after the study is desirable. Therefore it is necessary to develop a system which generates data on the safety of navigation and shipping efficiency. Especially casualty data and data on
inland traffic were lacking. A casualty database for the port of Rotterdam has already been
developed. A system is being developed for collection of data with respect to inland
navigation.

3. Results

Some results will be presented here, especially emphasizing economical aspects of safety and
efficiency.

- shipping traffic

The number of sea-going vessels entering the area at Maasmond varies around 33,000 per
year; this results in some 76,000 ship movements inside the port.
Each year approximately 120,000 inland barges visit the port of Rotterdam; this results in
about 300,000 ship movements. The average load capacity of inland trade increased
considerably over the last nine years, 3 or 4% per year. So, with an almost constant number
of ship movements the trade volume has been increasingly expanded.
Moreover the traffic density pattern has been determined as function of time during the
week. This pattern shows remarkable peaks round 6 o’clock a.m for incoming vessels and 6
o’clock p.m. for departing vessels.

In the past years there has been a change in the destination of ships in the port area. The
traffic to the Maasvlakte is fastly increasing. The traffic to the Europoort area also increases.
In total, this reflects the shift of port activities westward, towards deeper water.

- nautical accidents

With respect to the accidents that affect the nautical safety, approximately 75% of the
accidents are collisions of a sailing and a moored ship or a ship colliding with an object (i.e.
a quay, jetty, bank, lock or bridge) or running aground.
Most of the accidents take place in the harbour basins; it concerns practically only accidents
in which a sailing ship hits a moored ship or an object. On fairways, in comparison, also a
remarkable part of the accidents is due to two sailing ships colliding.

The following table shows the distribution of accidents after location and collision type:
### Table 1: Distribution of accidents after location

<table>
<thead>
<tr>
<th>Collision type</th>
<th>Fairways</th>
<th>Basins</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 sailing ships</td>
<td>10</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Sailing/moored ship</td>
<td>9</td>
<td>29</td>
<td>38</td>
</tr>
<tr>
<td>Ship/object</td>
<td>17</td>
<td>20</td>
<td>37</td>
</tr>
<tr>
<td>Others</td>
<td>4</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>41</strong></td>
<td><strong>59</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

For fairways a further study has been made to locate (possible) accident concentrations, as can be seen at figure 1, where the pattern of relative incident sensitivity is shown:

![Figure 1: INCIDENT SENSITIVITY](image)
On the Nieuwe Maas/Waterweg there are obviously two important accident sensitive areas:
- at the river near the city bridges and the mouth of the Maas- and Rijnharbours, and
- the branching of the Oude Maas.
- on the Oude Maas especially the area around the Spijkenisse- and Botlekbridges is sensitive to accidents.

Most of the accidents have minor consequences. Only 15% of the accidents is severe, implying noticeable damage to ship or cargo. This type of accident occurs comparatively more frequent in collisions where 2 sailing ships are involved. With increasing speed differences of ships at the time of the collision also the probability of heavy damage increases. On fairways in 17% of the accidents 1 or more ships is noticeably damaged, while in harbour basins this is 10%.

Almost 60% of the accidents takes place during winter because of the adverse wind- and fog conditions in that period. The possibility of an accident under conditions with strong wind or limited visibility is considerably larger than under normal conditions. For example before installing the new Vessel Traffic System, the probability of an accident with a visibility of less than 500 meters was four times higher than with a good visibility.

- cost of accidents

The most important components of cost as result of nautical accidents are: damage to port infrastructure and damage to ships. To get a complete picture also consequential damage should be encountered. However, this type of costs is hardly quantifiable as yet. The total damage to municipal properties (quays, piers, jetties etc.), governmental properties, privately owned quays and jetties and ships, resulting from nautical accidents can be estimated at roughly f 20 mln per year.

The mean damage cost of seagoing vessels dominates the mean damage cost of inland barges. Roughly spoken the mean damage cost differ a factor 10 to 20. This implies that the number of accidents where 1 or more seagoing vessels are involved dominates the total damage cost per year.

The following table shows the distribution of ship types involved and damage cost:
<table>
<thead>
<tr>
<th>ship types involved</th>
<th>distribution of accidents (%)</th>
<th>distribution of damage cost (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inland barge</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>2 or more inland barges</td>
<td>36</td>
<td>5</td>
</tr>
<tr>
<td>1 inland barge and 1 seagoing vessel</td>
<td>26</td>
<td>18</td>
</tr>
<tr>
<td>1 seagoing vessel</td>
<td>11</td>
<td>26</td>
</tr>
<tr>
<td>2 or more seagoing vessels</td>
<td>9</td>
<td>46</td>
</tr>
</tbody>
</table>

It can be concluded that 20% of the accidents results into about 70% of total damage cost. Due to the fluctuating number of accidents with seagoing vessels the total damage cost can fluctuate considerably from year to year.

**- delay costs**

In a shipping system turn-around and delay are important. The quality of the system can be measured by comparing the present situation to an ideal situation whereby any ship can enter or leave port any time. Of course, only the waiting times connected to the use of the nautical infrastructure are considered.

The most important components of those waiting periods are: waiting as a result of the application of an admission policy and those as a result of no pilotage.

For less than 5% of the ships visiting Rotterdam there is an admission policy due to tidal restrictions. The vast majority of the vessels that are subject to delays has an average delay time of one hour or less. About 5% of all vessels wait more than one hour, due to admission policy and suspension of pilotage.

To get an insight in the effect of delay, the delay is expressed in terms of turn-around time. The following figure shows that the average turn-around time is about 24 hours. Delay accounts for somewhat more than 2% of the turn-around time.
Although delay accounts for a very small increase in turn-around time for each individual vessel, for the total number of vessels visiting Rotterdam the cost is considerable. It amounts to between $f\,15$ and $20\,\text{mln}$ per year. It has been determined by multiplying the mean delay time, the mean cost per hour and the number of ships that is subjected to delays.

To get a feeling of the position of the Port of Rotterdam as far as delay times are concerned, we considered two hypothetical cases. Suppose that:

- Rotterdam would be situated behind locks;
- Rotterdam would have tidal restrictions for vessels with a draught over 34 ft.

In the first case the total delay cost would amount to $f\,85\,\text{mln}$ per year, assuming a relatively favourable handling time in the locks of 1.5 hours.

In the second case about 20% of all vessels would be subject to waiting times due to tidal restrictions, resulting in the estimated total annual delay cost of about $f\,40\,\text{mln}$. 

Figure 2: DISTRIBUTION OF TURN-AROUND TIME
The total actual delay cost of $f\ 20\ \text{min}$ in Rotterdam compares favourably with these figures.

system cost

As has been stated earlier, the following components can be distinguished in the nautical safety system: nautical infrastructure and nautical services.

At this moment a study is being carried out to determine which part of the cost of the infrastructure could be accounted to the nautical safety system. The picture is rather clear as far as the cost of the nautical services is concerned. Maintaining the distinction between VTS, patrol vessels, pilotage, tug service and linesmen, an inventory on the cost of nautical services resulted in the following:

<table>
<thead>
<tr>
<th>Table 3: Costs of nautical services</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Annual cost (Mfl.)</td>
</tr>
<tr>
<td>VTS</td>
</tr>
<tr>
<td>Patrolling</td>
</tr>
<tr>
<td>Pilotage</td>
</tr>
<tr>
<td>Tug service</td>
</tr>
<tr>
<td>Linesmen</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

4. Conclusions and recommendations

4.1 Summary

In summing up the results from the previous paragraphs, we arrive at the following picture:

- annual damage cost $f\ 20\ \text{Mfl}$
- annual delay cost $f\ 15-20\ \text{Mfl}$
- annual system cost $f\ 225-305\ \text{Mfl}$

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4.2 Conclusions

A number of conclusions can be drawn from this overview:

- The accident cost as determined in the previous paragraphs relate to the first category of accidents mentioned in chapter 1: the "daily" accidents. Due to the availability of a safety system, no large scale accidents or catastrophies have occurred in the past decades.
- Increasing the system cost cannot be justified from the point of view of decreasing damage or delay cost. Apparently the system is so sophisticated that the law of diminishing returns applies.
- The only reason for increasing system cost could be found in the dependency between the different accident categories: decreasing the number of "daily" accidents could decrease the probability of occurrence of large scale accidents and catastrophies. As yet we have no reason to believe that the present probabilities are too high.
- Apparently we should strive for an efficiency operation: decrease the system cost, while maintaining the present quality of the nautical services.

Moreover an economic evaluation of safety and efficiency can be useful for:
- categorizing accidents with respect to financial consequences (damage to infrastructure and ship), which probably will result into a more satisfactory classification of accidents
- defining criteria for acceptable admissibility of harbour basins after confrontation with user requirements. Moreover the admissibility of different harbour basins can be compared by determining the overall waiting cost.

4.3 Future actions

In setting out the course for such an efficiency operation the Rotterdam Municipal Port Management is taking the following steps:

Improving the Vessel Traffic System:
The VTS manages shipping, using all resources, such as the harbour patrol services, pilot
services, tugboat services etc. It is a decision-support system, enabling the traffic coordinator to decide and advise on movements of shipping. The VTS itself must enhance the quality of the port with respect to nautical safety and efficiency.

It has a vast information network, the Data Handling System. This is the administrative reflection of the actual performances in the port and can be seen as the real-time element of a Port Information and Management System (PIMS).

A PIMS is the Port Authority’s managerial tool for making the right decision at the right time. To make past experiences readily accessible. To set strategic goals, as the past affects and limits potential alternative future scenarios.

Introducing the Waterdepth Management System:

The Waterdepth Management System optimizes meteorological, current and water depth information as part of the data structure of the Vessel Traffic System. The objective is to provide the VTS operator with decisive information on hydro/meteo phenomena, its predictions and the influence on the keel clearance and/or tidal window of a defined vessel. So the system provides information on whether a ship with a defined draught (keel clearance) and a specific velocity, can enter the port safely from the harbour entrance to her berth and vice versa.

Introduction of the system will result in a more efficient operation, an increase of tidal windows and a consequent reduction of ship delay times.

Conclusion

In following the course described above Rotterdam expects to:

- maintain the high quality standards with respect to safety
- increase efficiency of shipping operations and reduce delay cost
- reduce cost of port safety
PROBLEM OF TRAFFIC SAFETY IN RUSSIA AND WAYS OF ITS SOLUTION

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Abstract

In Russia, problem of traffic safety is, actually, of extremely importance. According to statistics, practically all absolute and relative indices of accident rate has been increasing.

Change of the situation for the better is subject to complex development of transport infrastructure, which, unfortunately, is far behind the world level. In this view, radically new methods of approach to the points connected with ensuring of traffic safety are required. First of all, it concerns information processing and analysis; technical, financial, and legal securing; reliability of "human" and "road" factors and other questions on solution of which level of traffic safety can depend.

Problem of ensuring traffic safety is actually of the utmost social and economic importance in Russia. According to the experts' estimations, the losses connected with traffic accidents has many times exceeded those caused by train crashes, fires and other accidents. Yearly they average 20-25 milliard rubles.

Every twenty-four hours in the country occur about 540 traffic accidents, which result in more than 100 fatalities and 600 injured. Only during the last five years about 150 thousand lives have been lost and about 1 million persons have been injured in the accidents. From the beginning of this period number of perished and injured have increased accordingly by 75 and 35 %. Almost two thirds of the victims were of the able-bodied age. The total amount of traffic accidents increased for the same period by 40 %. Simultaneously their consequences have been making heavier.

During 1991 on the roads of Russia there 197.700 accidents occurred which resulted in 37.500 fatalities and 214.400 injured.

The main causes of the accidents were the following: drink driving, infringement of overtaking rules, exceeding the speed limits, indiscipline of pedestrians, non-usage of safety belts and crash helmets. In particular, every fourth traffic accident occurred through driving in drink. Share of the accidents caused by drunk pedestrians increased from 21.4 % in 1989 to 24.6 % in 1991. About 16.3 % of the cases occurred because of exceeding the speed limits and 15.5 % of them through wrong overtaking.
Scientific study of the problem shows dependence of the level and the state of accident rate upon socio-economic, political, climatic, historical and other factors including geographical, territorial-economic and demographic conditions.

In the making of the Russian State System, power and government, national system of traffic safety is being formed as well. In this period special attention should be paid to the inadequately developed traffic infrastructure, which is a result of late beginning of automobilization in Russia, on one hand, and the insufficient concern to the problem by the government on the other hand. To illustrate the problem we have cited below a few characteristics of some components of the traffic infrastructure.

In Russia, the territory of which is of 17075000 square kilometres the total length of hard surface roads is amounted only to 868000 kilometres. The roads were mostly built in accordance with obsolete standards and so, do not meet the requirements of traffic safety. When rising traffic intensity, unjustified cut in expenditure for road maintenance and repair work have led to deterioration of the road conditions.

At present, the means and methods used in traffic organization do not adequately answer the demands of road users. For instance, a problem of getting bearings has arisen in some cities of Russia.

However, the present state, conditions and equipment of the roads are expected to be improved in the nearest future. In the end of 1991 the Supreme Soviet of Russia adopted low "On Road Funds" providing for forming a special reserve for development and maintenance of the traffic network.

There is another problem connected with the fleet of motor vehicles which has been developed without due regard for the real state of the road network. The accepted idea of long-period automobile exploitation has led to laying the high-capacity service system consuming considerable material-technical and financial resources. That is one of the reasons of the automobile park aging. According to the experts' estimations, by 1995 more than 3,5 million automobiles will have reached the age of 15, i.e. the limit date of exploitation. It totals 80% of the automobiles which will have been produced by that time.

The arisen situation is, first of all, a consequence of erroneous approach to the problem of preventing traffic accidents when commanding-administrative measures have been taking without due regard for social, economic, technical and legal aspects of the problem. Besides, acuteness of the problem has not been realized completely.

Hashing up, over a long period of time, the actual state of affairs with traffic accidents has hindered from timely developing and taking appropriate measures. As a rule, measures proposed at different administrative levels has not been supported by financial, technical and economic resources. Efforts made to solve the traffic safety problem on the basis of rest financing and material-technical supply have turned this vitally important problem into the minor one. Moreover, neither activity coordination forms nor those of interrelations between different bodies involved have been determined.

No executors' responsibility has been established as well. As a result, majority of proposals has remained not fulfilled which still more
aggravated the situation. One of the consequences of such state of affairs is as follows. Accordingly to the low currently in force, responsibility for traffic accident occurrence is put solely on its participants, without damaging the economic interests of the authorities e.g. organizations—owners of transport facilities. Therefore, administration of overwhelming majority of such organizations has kept itself apart from taking road accident preventing measures or carried out purely formal activity in this area.

Low efficiency of the activity connected with introduction of a complex of national-wide measures aimed at traffic safety rising has prevented from successive lowering the traffic accident rate and reduction of heaviness of accident consequences.

Socio-economic, political and moral crisis of the society has sharply aggravated a great number of unsettled, for many years, problems which, in its turn, has negatively affected the accident rate in the country.

Ensuring traffic safety, especially in the present situation, is an important State problem connected with a number of complex economic, technical, legal, social, organizational, psychophysiological and pedagogical questions.

In the situation when practically all population is involved in highly intensive traffic and road accident preventing activity of varied and many-sided, a totally new approach to the problem of reduction of the road traumatism rate is required. Radical solution, however, can be found by introducing a new traffic infrastructure, development of complex programs and concentration for these purposes, of financial, technical and other resources on both republican and regional scales. At the same time a new State system of traffic safety ensuring should be established. Every administrative department, organization, institute official and physical person involved in this activity should occupy a strict position in this system. The system's functioning should be secured by the State authority.

In the experts' opinion, in the period of renewal of economic, legal and organizational relations it is necessary that the system should be developed at both national and regional levels.

To pursue the common State policy of traffic accidents preventing and reducing heaviness of their consequences a coordinating body is to be established at governmental level. Its duties are supposed to be the following:
- working out a conceptual basis of the State system of traffic safety
- development of national projects, programs and measures directed at prevention of traffic traumatism and reduction of national economic losses from traffic accidents
- making proposals on improvement of the economic mechanism of the projects implementation
- improvement of the legal regulations and the control system
- assistance in making use of the experience stored in the field.

Efficiency of management in the system of traffic safety ensuring depends to considerable degree, on completeness and reliability of information, operativeness in its getting, analysis and generalization as well as timely granting the necessary information to the interested bodies and persons.
Presently, in order to optimize information activity a program of computerization of management is being worked out. Automated registration of vehicles, traffic accidents, cases of violation of traffic regulations, driving licences, etc. is being introduced for this purpose.

Adoption of an effective low regulating relations in traffic sphere is another important step to solution of the problem of traffic safety. It is conceived that such basic statement should become a law of traffic safety strictly defining role and other subjects in the system of traffic safety. It is known that adoption of similar laws in a number of countries has positively affected their accidents rates. By the present moment, such law has already been drafted and submitted to the Russian Government.

In our view, the sharp drop in the traffic discipline is connected also with imperfection of regulations of the legislation currently in force, in particular, the code of administrative infringements. Lack of regulations allowing to take into account more completely factors defining personality of the infringer and to control the fulfilment of imposed penalties (e.g. fines or deprivation of the right to drive) gives many infringers an opportunity to avoid the responsibility. By now the Law "On introduction of amendments and additions into the Code of administrative infringements, the Criminal Code and the Code of Criminal Procedure" has already been drafted. The Law is to solve the situation arisen. This law in draft provides for disciplinary measures to a driver accurately corresponding to heaviness of this fault. It is also envisaged that a rate of fine should be proceeded from the minimum wage rate. Thus, the fine rate will be differentiated depending on monthly wage increase.

Moreover, recurrence of infringements of traffic regulations by a driver during a year is to be taken into account as well simultaneously, each infringement will be assessed according to a mark scale. Depending on the total mark, the infringer can be sent for a second examination or deprived of his rights to drive for the period from 3 to 6 months. The law in draft also provides for inevitability of punishment. So, in accordance with it, driving licence can be collected until the fine is paid or a resolution on deprivation of the right to drive is passed.

In our country a great number of questions of vital importance are regulated by statements issued by the Ministry of Internal Affairs. For the purpose of due regard for demands of observation of the human rights a number of normative statements is being carried out to submit to the Government's consideration. Among then there are the following: "Traffic Regulations", "Regulations of Vehicles Registration", "Regulations of Procedure of Granting Driver's Qualification", "Regulations of Automobile Inspection Procedure"

As it was mentioned above, traffic accidents occurring in our country are notable for high heaviness of their consequences. As it is seen in practice, there are many shortcomings in organization of first medical aid on accidents site. According to research data, more than 70% of deceases have come during a prehospital period or the first hospital hours. By reason of lack of traffic participants' skill those injured in accidents do not receive minimum aid before an ambulance car arrives. There is another important side of the problem which is connected with rehabilitation of injured in traffic accidents. Actually, very few attention is paid to this matter. In fact, in Russia there are no traumatological rehabilitation centers and operative and rehabilitation treatment is organized extremely irrationally.
As a result, 7% injured in traffic accidents become invalid. As for young and elderly persons, traffic accident consequences result for them in stable health disorder. The sited figures describe only a small number of the persons getting in such category. At the same time the problem is much deeper. Therefore, the actual aim is to do so that physical and mental traumas got in traffic accidents would stop pursuing a man during all his life. In our view, that will be a direct contribution to reorganization and stabilization of the society.

Training of drivers and improving their skills is one of the most important factors affected the level of traffic safety. However, working in Russia training system is not enough effective.

With the purpose of improving driving skill certain efforts are being made. In particular, a complex of methodical and information materials providing for individual training on the basis of situational approach to learning traffic regulations and working out safe driving skill has been developed. It is supposed that a valuable contribution to this cause should become extensive counter-accident training of both professional and amateur drivers. To realize the idea production of quite simple and cheap equipment, appliances and trainers is to be launched. It is also necessary to improve further educational and instructor personnel training with higher educational establishments working in this field. A new profession of engineer-teacher is to be acquired in these institutions. The first steps in this direction have already been taken by the Ministry of Internal Affairs jointly with the Ministry of Education.

System of drivers training and improvement of their skill must be oriented at different categories of drivers. Besides, it must be linked with national economic and apply research results and experience gained in the field of traffic safety.

Within organization of drivers training not the least part is assigned to examination. An efficient objective examination system will promote competitiveness of training methods worked out in different higher educational institutions in which there are available high skilled teaching personnel and appropriate material resources.

It is impossible to succeed in lowering the traffic accident rate without organizing general teaching of traffic regulations and making a mechanism of their implicit performance. Actually, traffic regulations in the Russian Federation are being taught only in primary school and preschool institutions.

For the purpose of inculcating a habit of safe behaviour in traffic situation in adults, mass information media and visual aids are generally used. It is quite evident that these methods have already become old. In the nearest future, we will have to do much work for their improvement, so that every citizen would be aware of social importance of compulsory maintenance of traffic regulations.

One of the main directing bodies responsible for ensuring traffic safety in Russia is the State Motor Licensing and Inspection Department under the Ministry of Internal Affairs. The Department is in control over observance of regulations and standards currently in force.

We are looking forward to establishing mutually advantageous relations with foreign organizations with a view of making joint efforts aimed at
lowering traffic accident rate through exchange of information and positive experience between Russian road police and those of West European countries and other ways of cooperation in the field of traffic safety.
RISK REDUCING MEASURES AS AN ESSENTIAL PART OF RISK MANAGEMENT

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Abstract:

In 1990 the Ministries of Transport and for Housing, Regional Development and the Environment in the Netherlands started the project: Risk Standardization Transport Hazardous Substances.

The Committee Transport Hazardous Substances (CTGG) is a member of the Reference Group in that project. CTGG quantified the value of several risk reducing measures. Many of these measures are implemented in the transport of hazardous substances. Thanks to them the transport of hazardous substances is one of the safest activities taking place in our society. For example, it is dozens of times more safe than the transport of non-hazardous load. CTGG quantified the value of several risk reducing measures to be divided into four main areas:

- organizational,
- technical,
- infrastructural, and
- regional development.

Data needed for quantification were sampled by:

- casuistics;
- logical reasoning and calculation;
- expert analysis, and
- "The Manager Technique".

CTGG considers these measures an essential part of the evaluation of the remaining risks of the transport of hazardous substances. They could also be used in making other types of transport more safe.

Follow-up of the measures can be guaranteed by assurance of safety by ISO 9002 certification with and adjoining NEN 2726.

In this paper a survey of the CTGG investigation is given.

1. Introduction:

Whenever we are talking about the transport of hazardous substances, the term "hazardous" is catching our immediate attention, rather than the term "transport". People are getting feelings of uneasiness when considering their chance of being involved in an accident. The negative approach of this transport is unmistakable. Often it is said that this way of transport ought to be prohibited.

Disasters like the catastrophe at Los Alfaques in 1978, as well as accidents such as those near Herborn in 1987 have furthered this.

Yet we should avoid any policy based on accidents of rare
occurrence. This is why we have to know how risky the transport of hazardous substances really is.

Although we have no reliable databank where accidents with hazardous substances are recorded, it is a fact that transport of hazardous substances is among the safest activities taking place in our society, for many years already substantially safer than the transport of non-hazardous goods. And the latter again is many times safer than traffic by passenger car.

Notwithstanding the factual evidence of the transport of hazardous substances being very safe, government and hauliers/carriers are continuously working on further improvement of quality and safety of this kind of transport.

In the Netherlands a study is being made into the quantification of the risk of transport of hazardous substances, a study co-ordinated by the Ministries of Transport and for Housing, Regional Development and the Environment. This study will eventually lead to standards in this domain being set. To support the study a reference group has been established, in which all parties interested are represented. Hauliers and shippers are being represented through CTGG, the latter having a project group CTGG-QRA (Quantitative risk analysis) which is contributing specific knowledge on this matter. Results of the study can be influenced by both chance and effect determining measures. CTGG has set itself the target of coming out with information for both these domains. In their report they present an investigation into the effect of technical and organizational measures. At the same time possibilities for the government are mentioned in order to increase safety by way of infrastructural measures, as well as measures in the domain of regional development.

Quite a number of the main technical measures has been studied by a working group from CTGG-TA. Methodology applied was together with results laid down in Chapter 3. In Chapter 4 part of the organizational measures is mentioned. Therefore, a quantification methodology has been used as described in the Manager Technique (developed by Technica Ltd.) in combination with the requirements as stated in draft standard NEN 2726 (safety requirements for road transport of hazardous substances in bulk).

2. A model of QRA, within which the reduction factors of risk restricting measures can be expressed:

Before talking about quantitative risk analysis (QRA) we have to realize that QRA does not give us an easy tool to take the right decisions about standards for safe trans-
port. Risks associated with transport cannot be measured and analysed like for instance the exhaust of motor cars. At the best QRA will give indications of risks. QRA cannot be a substitute for judgment of managers and governmental authorities. QRA can be an aid to give us a deeper understanding to compare risks on a more defined basis.

If quantitative risk analysis is applied by us to road transport, for instance, this could be done as follows:

(Note: The figures used in the model are as realistic as possible, but have been arbitrarily assessed!)

\[
\begin{array}{cccccccccccc}
A & 1 & 1 & 1 & 2 & 1 & 1 & 0 & 0 & 8 & 0 & 1 & B \\
\end{array}
\]

The route from A to B has been subdivided into fixed route sectors of 1 km each. For 3 consecutive years accidents have been recorded by route sector. In the route sector indicated by the arrow there appears to be a bottleneck where in a three-year period 8 accidents occurred, so the average is 2.67/year.

From countings it appears that the annual amount of vehicles passing by is 1,000,000, of which 1,000 (x) are carrying hazardous substances.

Moreover, statistical material shows that the chance of a passenger car getting involved in an accident is 4 (b) times that of a lorry. At the same time it has been statistically established, that the chance of a vehicle carrying hazardous substances will get involved in an accident is 25 (c) times as small as that of a lorry with non-hazardous load (*). Finally statistics show that the chance of hazardous substances being released in an accident is 0.1 (d).

Thus the chance (P) of hazardous substances being released at the bottleneck mentioned before, is:

\[
P = \frac{2.67 \times 1000 \times 1 \times 1 \times 1}{1,000,000 \times 4 \times 25 \times 10} = 2.67 \times 10^{-6}/\text{year}
\]

(*) Factor 1/25 has been derived from a comparison of tables 1 and 2 in Dutch Lower House paper Nr. 15815 (1979-1980).

Next it should still be calculated effect (e), and from that the chance of damages expressed in casualties to be regretted, by means of a "Probit-function".
(e) is among other things dependent on:

- nature of the substance released
- flow-out velocity and quantity of the hazardous substance
- average traffic density in situ
- distance from road sector to surrounding residential area
- wind direction, wind velocity and weather conditions.

Nature of the substance:
It will be understood that the effect of a flammable gas like LPG being released will be of greater impact than of petrol being released. And the effect of a poisonous gas like ammonia is again greater than of a corrosive and poisonous liquid like hydrochloric acid.

We can classify the effect according to "limiting value". The latter is expressed in the amount of kilograms of the substance, which can have a lethal effect even at 100 m distance. This limiting value has to be corrected by "circumstantial factors" such as:

- explosivity (LEL);
- flammability (1-4);
- toxicity (LC-50 value);
- state of aggregation at 25 °C;
- atmospheric boiling point.

So, in order to be well able to determine the risk in road sector(*), we shall have to classify the hazardous substances in the vehicles passing by, by limiting value. The substances with the lowest limiting value corrected are here assessing for both the individual and the societal risk. Of course, the quantity conveyed is also of great importance.

Let us assume that 1% of the hazardous substances could be released in quantities exceeding the limiting value. In that case people being at a distance of over 100 m around the accident could meet with death. Personal mortal risk \((P \times e)\) at 100 m distance of the road sector involved (*) could in the model shown before be \(2.67E-8\) year. Depending on the amount released, as well as on the flow-out velocity, fatal consequences can spread over a larger distance.

In order to be able to assess the societal risk, a few other factors should be taken into consideration also; among the latter are those already mentioned:

Traffic density, distance to residential areas, as well as wind direction, wind velocity and weather conditions. It will be obvious that traffic density and residential areas around the place of the accident are decisive for
the number of people in the group, which can become victims. Moreover, weather conditions determine in what direction, at what speed and to what extent the hazardous substance can make people be its victims.

For an assessment of the impact of these factors, models have been developed which will not be further dealt with within the scope of the present report. Together with the above-mentioned personal risk, these models allow the calculation of the group risk. The latter is usually made visible in a diagram, in which on the vertical axis the chance of death per year (f) is plotted, and on the horizontal axis the effect stated in number of deaths per accident (N). The line in the diagram representing the connection between frequency and number of deaths is called the fN curve.

Influence of risk reducing factors on the above-mentioned model:
In the model it is understood that:

(a) = chance of accident per vehicle passing road sector
(b) = correction factor of lorries versus passenger cars
(c) = correction factor of vehicles carrying hazardous substances versus lorries with non-hazardous load
(d) = chance of hazardous goods being released, indeed, in case of a vehicle carrying hazardous substances being involved in an accident
(e) = chance of fatal effect.

(a) thru (e) are the factors determining the eventual risk. It may be obvious that the values given in the model mentioned before, of e.g. (b) and (c) are the resultant of numerous risk reducing factors of measures already taken.

(a), (b) and (c) - and partly (d) and (e) also - can like (x) be statistically established by means of registration per road sector. To that end the duty to report severe accidents has to be legally regulated.

The risk reducing measures that have been (or can still be) taken, especially have a reducing impact on factors (c), (d) and (e), however in some cases on (b) also.

In Chapter 3.1 the above-mentioned factors are by way of example referred to.

3. Effect of technical measures:

The data required to establish the value of a certain measure as a risk reducing factor can be derived from one
of the following categories:

* casuistics
* rational argumentation and calculation
* assessment by the Delphi method, which can be so-
  phisticated by the Bayes method (S. French, id. 1991)

The effects described in this chapter, of technical measu-
res have been determined to the best of their knowledge
and capability by a small working group from CTCG-TA.
Preference was given to calculating the risk reduction
factor on the basis of one of the first two categories.
Wherever this was not possible, the calculation was made
by more or less using the third method. The values asses-
sed are gladly recommended for further improvement.
Perhaps this design can be made more sophisticated by one
of the Dutch universities, while at the same time the
level of accuracy could be raised.

Following technical measures have been quantified:

3.1 Speed limiters
3.2 Material choice
3.3 Wall thickness
3.4 Double valves
3.5 New or remould tyres vs covered
3.6 Additional lighting
3.7 Explosion-proof electrical equipment
3.8 Insulation
3.9 Compartmentalization
3.10 Front, side and rear protection
3.11 Lowest possible centre of gravity
3.12 Daily technical check by means of checklist
3.13 General Car Inspection (APK) and ADR inspection
3.14 ABS (anti-lock device) and ASR (drive slip control)
3.15 Double shelled tankers
3.16 Radar units
3.17 Stability requirements
3.18 Cooled transport
3.19 Safe coupling
3.20 Preventive/curative valve maintenance
3.21 Load-dependent braking system
3.22 Remote-controllable valves
3.23 Retarders

As today there is not enough time to deal with all measu-
res examined, it is here given an example only.

3.1. Effect of speed limiters:

In the model involved speed limiters do have an influence
on (b) and (d).
to (b) Let us assume that average maximum speed of lorries on highways will decrease from 90 to 80 km/h. In case of an emergency stop, braking distance will reduce from an average 81 to 64 m, that is 20 per cent. Reduction factor for (b) consequently is 0.8 (In the model (b) would be reduced to 0.8 x 0.25 = 0.20).

to (d) Crashing speed is likewise decreasing by at least 20 per cent. According to Westbrook (abt. 1975) there is a linear relation between crashing speed and the chance of wall penetration. So the reduction factor for (d) is also 0.8. (In the model (d) would be reduced to 0.8 x 0.1 = 0.08).

As at the same time there will occur less overtaking by lorries and thus their drivers will be exposed to much less stress, actual reduction will definitely further increase. If it is assumed that in this way another reduction of 0.8 is achieved, total risk reducing value will be 0.8 x 0.8 x 0.8 = 0.5.

The effect of this measure in the model is, that the chance of a hazardous substance being released is halved down to 1.33E-6/year.

4. Effect of organizational measures:

For organizational measures it often is more difficult to quantify their effect than for technical ones. This is due to the fact that these measures mostly consist of human activities or are aimed at regulating human activities. As you will know, human errors are to blame for over 80% of the accidents, which means that with respect to organizational measures performance by motivated personnel and checks on compliance are decisive.

Responsibility for these checks rests with the authorities on the one hand and with performing management on the other. We feel that compliance with the measures in question can best be warranted by certification of quality with and adjoining safety in conformity with ISO 9002. The certifying body will then carry out half-yearly systematic checks on performance. At the same time the certificate is to be renewed every three years. Safety requirements have been laid down in NEN standard 2726. In 4.1 a methodology is described that may serve to quantify the factors having their impact on human acting. Here it has been used the Manager Technique of Technica, as well as NEN standard 2726.
4.1. Short description of the Manager Technique:

On the basis of extensive accident research for fixed plant units it is possible to divide the factors with an impact on human acting, into four main influence areas:

- system norms (standard conditions and procedures)
- pressures or stress factors (critical, monotonous conditions)
- resources (personnel, materials, instrumentation, etc.)
- communication

The influence areas can be divided into several domains of attention. For each influence area there is a questionnaire being filled out on the basis of a scoring system. Checklists, questions and descriptions are used to establish the score in terms of good, bad, average. "Average" score is set at a multiplication factor of 1, "bad" at 100 and "good" at 0.1. This gives a variation of 1,000 fold from best to worst, which is in line with the range of actual failure frequencies observed in plant components. Bad scores can thus have a substantial impact on total results, so the improvement is very well visible. To the four domains of influence a specific weighing factor can be allocated according to relative importance to the entity, however each underlying factor per domain of attention being of equal weight.

Input data are ultimately combined to the fractions 'good', 'bad' and 'average', and then filled out in a triangular diagram. This gives us a resulting "Multiplication Factor" that can be used to influence the general probability figure.

4.2. Adjustment of the "Manager Technique" for Transport:

A linking has been realized between the domains of influence mentioned before, from the "Manager Technique" and the requirements described in NEN standard 2726. Once again it would be getting too far off the subject, if we should further elaborate the whole methodology in this paper. Let it suffice to show you a triangular diagram in which it is given the final result of an audit of a haulage company.

The diagram is based on a table in which a score is given of 59 domains of attention divided into the above-mentioned four influence areas. The scores were generated by group judgment.

The resulting score in the domains with a good proportion was 0.788; with an average proportion 0.132 and with a bad proportion 0.08.
In the triangular diagram the fractions have been filled out and the factor was established (see Annex 1).
The result of this audit is a multiplication factor of 0.45.

A complete description of the study on which this paper is based is described in CTGG report: Quantification of risk reducing measures of the transport of hazardous substances.

References:

Dutch Lower House paper Nr. 15815, Netherlands, (1979-1980)


CTGG, Quantification of risk reducing measures of the transport of hazardous substances, (to be published in the Dutch language by Samsom H.D. Tjeenk Willink, Netherlands, (1993)).
A COMPREHENSIVE ASSESSMENT SYSTEM FOR THE MARITIME TRAFFIC ENVIRONMENT

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Abstract

It is desirable when drawing up a maritime traffic environmental project or a project for consolidating port and harbour facilities that the safety of the maritime environment for shipping traffic is assessed quantitatively, and the rationale of a given project and the proposed safety measures are evaluated in an objective manner.

In this report, the system flow and procedures to integrally assess the safety of the maritime traffic environment by systematically combining various simulation techniques are discussed first.

Subsequently, the quantitative risk evaluation procedure for collisions of ships in waters with a high traffic density among the assessment procedures above and an outline of the shipping traffic flow simulation capable of reproducing ships' movements are described. In evaluating the results of simulations, a method introducing subjective judgement values (SJ values) as indexes manifesting the subjective degree of danger felt by shiphandlers is shown. The SJ values were experimentally determined from simulator experiments using parameters representing the relationship with other ships proceeding in the vicinity.

Lastly, some of the results of studies conducted for the recent construction of new LNG berths in Tokyo Bay are introduced as an example of practical safety assessment in this field.

1. Introduction

Memories are still fresh among shipping concerns of the grounding and massive oil spill of an oil tanker in Alaska, of the collision between an LPG tanker and a cargo freighter involving a fire in Tokyo Bay, and the collision of a large ship with a trunk road bridge in Brunswick, Georgia. If multiple major marine casualties occur, the impacts on the natural environment and society are immeasurable. On the other hand, it is very important for sound socioeconomic development to utilize the sea for marine airports, roads, bridges, pleasure bases, fish culture, etc.
To draw up plans for new maritime traffic systems and port and harbour facilities, it is necessary to quantitatively grasp the safety of the shipping traffic environment, and to evaluate the rationale of the plans and the proposed safety measures. Several simulation techniques have been developed and put applied to help quantitatively grasp the safety of the shipping traffic environment. Demand for a sophisticated system combining these simulation techniques to ensure an integrated assessment of the safety of the shipping traffic environment is expected to increase in the future. This report discusses a procedure that assesses the safety of the shipping traffic environment in an integrated manner.

2. Flow of a Safety Assessment System for the Shipping Traffic Environment

Fig. 2-1 is a schematic of a general system that assesses the safety of the shipping traffic environment in relation to a marine transport project. This represents the flow of the safety assessment system using the simulation techniques proposed and developed by the authors of this report, which recently have almost taken form as the standard safety assessment system of the shipping traffic environment applicable to marine transport projects or consolidation plans for port and harbour facilities in Japan.
The flow of the safety assessment system can be broadly divided into the following three:
- Assessment of the rationals for a marine transport plan
- Assessment of the degree of danger of collisions in a specific sea area, and assessment of the traffic volume in a traffic route
- Assessments of shiphandling environment and port and harbour facilities

The contents of the assessment are outlined below:

2.1 Assessment of the rationale of the transport plan

In assessing a marine transport project, the volume of marine transport and means of transportation are assessed, and simulations are carried out on the operating rate of berths using the theory of queue management including the relationship between the marine transport potential and the capacity of the shore reception facilities. Through these assessments, the optimum balance between the transport plan and the capacity of reception facilities, without having a significant number of ships waiting outside a port, can be sought. Fig. 2-2 shows an example of the simulation output plan indicating the berth operating rate in a coal transport project.

![Simulation output plan](image)

Fig. 2-2 A simulation output plan to assess the operating rate of berths

2.2 Collision risk assessment of a sea area and traffic volume assessment in a traffic route

For a newly projected marine transport plan, if ships proceed through straits and waters close to large ports and bays with a high traffic density, it is necessary to carry out a collision
risk assessment and a traffic volume assessment. Based on the results of these investigations, the significance of the effects of increased collision risk caused by the marine transport plan upon the sea area of high traffic congestion, and whether or not the capacity of the traffic route has any allowance are evaluated, and the acceptability of the proposed marine transport plan is judged from the viewpoint of traffic congestion. In collision risk assessments, passages what routes and what time belts are most desirable from the viewpoint of the safety of shipping traffic are specifically studied.

In assessing the degree of traffic congestion, it is necessary to extract sea areas on the basis of the new marine transport plan for surveying actual traffic conditions. This survey is intended to grasp the number of ships involved, ship’s tracks, and speed using radars. Based on the results of the survey, predictions are made on the impact of other projects upon marine traffic and probable shipping volume due to the trend of the economy, and simulations are carried out to assess the risk of collisions and to estimate shipping traffic volume in the future. The simulations include a marine traffic flow simulation to assess collision risk, the shipping traffic volume simulation to estimate traffic volume, and a traffic control simulation to investigate the need for shipping traffic control. The shipping traffic flow simulation and its evaluation method are discussed in greater detail in Chapter 3.

Fig. 2-3 is a ship track chart drawn on the basis of the results of the shipping traffic survey carried out off the Port of Yokohama using radars. These results of experimental surveys serve as the basic data for preparing the shipping traffic flow simulation model to be described later.

Fig. 2-3 Results of Shipping Traffic Investigation
2.3 Assessments of Shiphandling Environment and Port and Harbour Facilities

In assessing the shiphandling environment and the port and harbour facilities plan, systematic experiments are carried out using shiphandling simulators capable of generating realistic images of marine facilities, aids to navigation, and natural environment with moving objects in their relation with degrees of difficulty in shiphandling giving a strong on-the-scene feeling in the wheelhouse. In evaluating degrees of shiphandling difficulties, the shiphandling process is divided into the course-keeping phase, course-changing phase, headway killing phase, turning phase, and the phase of lateral ship motions, each of which serves as an element of evaluating shiphandling difficulties. For each such evaluation element, the principal evaluation elements and principal evaluating indexes are determined, thereby an evaluation of shiphandling difficulties is carried out on the results of simulator experiments under various conditions. Fig. 2-4 shows photos covering simulator experiments. As examples of shiphandling difficulty evaluation index, the distribution of deviation at the point at which the shiphandling phase changes from one phase to another (tentative goal) is shown in Fig. 2-5. These are the deviation of ships at the tentative goals compared with the results of shiphandling involving external forces and errors with the standardized shiphandling results (shiphandling without involving external forces and errors). The ellipsoid drawn in dotted lines in the Figure shows the allowable limit of deviation under the general interactive relationship between the shiphandler and marine facilities.

To assess the safety of a ship while laying alongside a berth and the limits for cargo operations, studies are conducted by the laid ship motion simulation. In this simulation, the motions of a ship in wind, waves, and swells are calculated with six degrees of freedom, whereby the safety of a ship laid in motions is assessed from the mooring rope tension and the movements of the ship due to motions.

Fig. 2-4 Photos showing shiphandling simulator experiments
3. Collision Risk Evaluation with a Marine Traffic Flow Simulation

In marine transportation, the collision risk evaluation is an important assessment item from the viewpoint of assessing safety because shipping traffic is two-dimensional and speed regulation is difficult. From the evaluation systems stated in Chapter 2, degrees of collision risk, and items for assessing the degree of traffic congestion are discussed in detail as below.

3.1 Outline of Marine Traffic Simulation

Setting the detailed explanations on simulation models aside, the marine traffic simulation introduced here grasps the traffic environment in a specific sea area quantitatively on the basis of the meeting situation of ships, and giving-way manoeuvres, and has the following features:

- All ships navigating in the simulated sea area proceed with an algorithm that carries out collision averting manoeuvres close to real shiphandling for collision avoidance. It is, therefore, feasible to reproduce the shipping traffic very close to the real image on the simulator display.

- Not only the collision risk evaluation of the entire sea area under study, but also the judgement standard for collision risk computed on the basis of the results of the shiphandlers' consciousness survey (simulator experiment) are incorporated into the ship for which the generation of collision risk is to be proved. Because the ship to be evaluated is selected according to such a standard, the results obtained are very close to the judgement made by experienced shiphandler.

3.2 Simulation Examples

A certain degree of dispersion is created for the encounter of ships in this simulation because random numbers are used for simulating the ships involved. It is necessary to simulate as many meeting situations as possible to reduce the dispersion. It was, therefore, established that calculations were repeated
for each simulation until a total of 2000 ships were generated. The time intervals for generating ships and collision judgements were five seconds. The ship track chart simulated is shown in Fig. 3-1.

![Fig. 3-1 Simulated Ship track charts](image)

**3.3 Evaluation Method for Simulation Results**

As the index to evaluate the degree of difficulty of average shiphandling in an experimental sea area, the number of collision-averting manoeuvres carried out in the ship in a marine traffic flow simulation, or the mean value of the number of collision-averting manoeuvres of the other ship can be mentioned. However, in assessing the safe navigation route for a ship or the safe time belts, an evaluation of collision risk from the viewpoint of the ship to be investigated is necessary. And, the evaluation must reflect the shiphandler's consciousness. Factors indicating the degree of collision risk felt by the shiphandlers are determined experimentally, and the results of the simulation were evaluated by applying the equation of the evaluation comprising these factors. The contents are shown below.

**3.3.1 Subjective collision risk felt by the shiphandler**

As an index to express the degree of collision risk of a ship felt by the shiphandler, the concept of Subjective Judgement (hereafter called the "SJ value") was introduced in this study. The SJ value expresses quantitatively the degree of collision risk with another ship felt by the shiphandler. The parameters were assessed experimentally, and the following equation of evaluation (1) was introduced with variables: the relative distance between the ship and another ship, the rate of change of the relative position of another ship viewed from the ship, and the relative speed between the ship and another ship.
\[ SJ_i = a_i \Omega + b_i R' + c_i \dot{R}' + d_i \]

where,
- \( SJ_i \): subjective judgement value (i=1~4; the No. is division classified by relative course)
- \( V_r \): relative speed
- \( L \): length of the ship (m)
- \( V \): ships speed (m/sec)
- \( \Omega \): non-dimensional rate of change of relative directions
- \( R \): relative distance
- \( R' \): non-dimensional relative distance (\( R' = R/L \))
- \( \dot{R}' \): non-dimensional approaching speed (\( \dot{R}' = V_r/V \))
- \( a_i, b_i, c_i, d_i \): coefficient of each parameter

The equation above is expressed as a regression equation with the shiphandler as the subject, and the relationship with the three variables, i.e., the collision risk, rate of change in relative directions, and relative distance by collecting data experimentally using the shiphandling simulator.

In obtaining the regression equation, it was considered that the collision risk varies according to the meeting situation, and this was classified into the following four groups by relative course between the ship and another ship:

- \( i = 1 \): meeting end on
- \( i = 2 \): proceeding same way
- \( i = 3 \): crossing from starboard side
- \( i = 4 \): crossing from port side

The SJ values and the degree of collision risk felt by the shiphandler have the following relationship:

- Extremely dangerous: \( SJ = -3 \)
- Dangerous: \( SJ = -2 \)
- Slightly dangerous: \( SJ = -1 \)
- Cannot say which: \( SJ = 0 \)
- Slightly safe: \( SJ = 1 \)
- Safe: \( SJ = 2 \)
- Extremely safe: \( SJ = 3 \)

3.3.2 Evaluation index

Examples of an evaluation index using the SJ value are shown here.

The concrete results of evaluation are stated in Chapter 4.

- Number of encounters per unit time with ships whose SJ value is \(-1\) or less.

This is the number of encounters with ships calling the attention of the ship under study. The SJ values of a ship for other ships are computed constantly during the simulation period, and the number of encounters with the ship (calling the attention) whose SJ values (subjective degree of collision...
risk) becomes a threshold value ($SJ \leq 1$) is integrated, and by dividing this by the integrated value of hours run, whereby the number of encounters per unit time (e.g., 10 minutes) is obtained. By this procedure, a quantitative evaluation comparable to the real feeling of the shiphandler becomes possible.

- SJ value distribution chart

The sea area under study is divided into meshes. The SJ value making the degree of collision risk to be $-1$ (slightly dangerous) or less is integrated for each mesh according to the following equation. The result thus obtained is divided by the simulation time and expressed by a shaded graduation on the SJ value distribution chart.

The SJ value distribution is expressed by Equation (2). By looking at the shaded graduation of meshes on this distribution chart, where in the sea area under study is the number of encounters with ships calling for the highest attention can be identified.

$$SJ \text{ value distribution value} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} (|SJ'_{m,i} - 1| \cdot t)}{60 \cdot T}$$

where,
- $SJ'$: SJ value under a threshold value ($SJ$ value $\leq -1$)
- $n$: number of ships navigated during the simulation
- $m$: number of calculating SJ values during the simulation
- $t$: calculation step time intervals for SJ values (sec)
- $T$: simulation time (min)

4. Examples of Safety Evaluation Examples for the Shipping Traffic Environment

Examples of the safety evaluation implemented by using the evaluation systems described above are introduced here taking up some recent assessments in Japan.

The object studied is a project to construct a new LNG berth in the vicinity of the Port of Yokohama within Tokyo Bay for large LNG carriers.

Firstly, the scale of the projected berth and the planned volume of LNG carried were assessed and concluded to be trouble-free. In assessing the degree of traffic congestion, the capacity of traffic volume in the URAGA SUIDO Traffic Route located near the mouth of Tokyo Bay was investigated. The results of the investigation showed that the estimated traffic volume would reach a critical point depending on time belts, and concluded that the passage of large LNG carriers through the Traffic Route should be scheduled to avoid the time belts when the shipping traffic is particularly heavy.
In assessing the degree of collision risk after passing URAGA SUIDO Traffic Route, investigations of safe routes for entering port manoeuvres up to the planned berth and time belts of passage were carried out using the SJ values stated in Chapter 3. Fig. 4-1 shows the distribution chart of SJ values viewed from the ship under study (incoming LNG carrier) when she proceeds along the northern route for entering port manoeuvres in the time belt with the highest traffic density. Fig. 4-2 shows the distribution chart of SJ values when the ship proceeds along the southern route in the same time belt. Table 4-1 is a list of the number of encounters making the SJ values in 10 minutes to -1 or less. These results show that the northern route for entering port manoeuvres is safer. The highest value of the mean number of encounters in 10 minutes (SJ values less than -1) was 5.2 for the southern route for entering port manoeuvres from 1400 to 1500 hours. Recognizing the general principle introduced from the simulator experiments that if the number of encounters with ships calling for attention in 10 minutes exceeds 5, shiphandling becomes difficult, the time belt for entering port manoeuvres through the southern route was established to be before 1000 hours, and that the passage through the northern route for entering port manoeuvres would be desirable for safety reasons.

![Fig. 4-1 SJ value distribution of LNG carriers on the northern route](image1)

![Fig. 4-2 SJ value distribution of LNG carriers on the southern route](image2)
Table 4-1 Number of encounters with ships calling attention (SJ value: -1 or less) as viewed from the ship under study

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean No. of ships encountered (SJ &lt;= -1)</th>
<th>Standard deviation</th>
<th>Ship under study No. of ships generated</th>
<th>Ship under study Mean time of passage (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07-08</td>
<td>1.9</td>
<td>0.77</td>
<td>35</td>
<td>68.9</td>
</tr>
<tr>
<td>08-09</td>
<td>1.0</td>
<td>0.43</td>
<td>55</td>
<td>68.8</td>
</tr>
<tr>
<td>09-10</td>
<td>1.8</td>
<td>0.82</td>
<td>52</td>
<td>71.5</td>
</tr>
<tr>
<td>10-11</td>
<td>2.4</td>
<td>1.19</td>
<td>33</td>
<td>69.5</td>
</tr>
<tr>
<td>11-12</td>
<td>2.3</td>
<td>1.05</td>
<td>36</td>
<td>69.1</td>
</tr>
<tr>
<td>12-13</td>
<td>1.8</td>
<td>0.94</td>
<td>40</td>
<td>70.6</td>
</tr>
<tr>
<td>13-14</td>
<td>1.2</td>
<td>3.67</td>
<td>48</td>
<td>70.5</td>
</tr>
<tr>
<td>14-15</td>
<td>2.7</td>
<td>1.70</td>
<td>40</td>
<td>68.9</td>
</tr>
<tr>
<td>15-16</td>
<td>2.2</td>
<td>1.01</td>
<td>38</td>
<td>69.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean No. of ships encountered (SJ &lt;= -1)</th>
<th>Standard deviation</th>
<th>Ship under study No. of ships generated</th>
<th>Ship under study Mean time of passage (min.)</th>
</tr>
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<tr>
<td>01-08</td>
<td>3.5</td>
<td>1.28</td>
<td>36</td>
<td>57.5</td>
</tr>
<tr>
<td>08-09</td>
<td>2.7</td>
<td>0.63</td>
<td>55</td>
<td>58.7</td>
</tr>
<tr>
<td>09-10</td>
<td>2.9</td>
<td>0.52</td>
<td>51</td>
<td>63.1</td>
</tr>
<tr>
<td>10-11</td>
<td>4.0</td>
<td>1.23</td>
<td>33</td>
<td>59.0</td>
</tr>
<tr>
<td>11-12</td>
<td>4.0</td>
<td>1.21</td>
<td>36</td>
<td>58.6</td>
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<tr>
<td>12-13</td>
<td>3.6</td>
<td>1.65</td>
<td>49</td>
<td>59.0</td>
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<td>13-14</td>
<td>4.2</td>
<td>1.92</td>
<td>49</td>
<td>59.1</td>
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<td>14-15</td>
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<td>59.7</td>
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<tr>
<td>15-16</td>
<td>3.5</td>
<td>1.54</td>
<td>38</td>
<td>58.1</td>
</tr>
</tbody>
</table>

For assessing the shiphandling environment and the port and harbour facilities, the geometric configurations and the orientation of the planned berth were fully investigated by shiphandling simulators and mooring simulations. As a result, the preferred geometric configuration of the berth, critical sea and weather conditions, required power capacity of tugs and number of tugs were recommended. Examples of ship track charts chosen from the results of the shiphandling simulator experiments are shown in Fig. 4-3.

5. Concluding Remarks

To quantitatively grasp the safety features of the maritime traffic environment involved in a marine transport project or a consolidation project of port and harbour facilities for assessing the rationale of the projects and the proposed safety measures in an objective way, a variety of simulation techniques have been systematically combined and overall safety was investigated through the flow of assessing systems shown.

As an integral part of the assessing system, the marine traffic flow simulation was outlined, and the collision risk evaluation method was described. A technique to express the
subjective degree of danger (SJ value) felt by the shiphandler using parameters such as the relative distance to another ship and the rate of change in the direction was shown, whereby the results of the assessment of the sailing route of a ship and passing time belt using SJ values were exemplified. Not only the collision risk assessment as a mean value of the entire sea area under study, but the subjective degree of collision risk as viewed from the ship under study could be expressed in a form close to the real feeling and consciousness of the shiphandler. As a result, the effectiveness of the assessing system could be demonstrated.

As an example of an assessment of the safety of the shipping traffic environment, part of the results of the safety assessment for the plan to construct a new LNG berth in Tokyo Bay, Japan was shown.

The authors of this report wish to mention before concluding that the authors have advocated an idea that if SJ values for assessments introduced at this time could readily be understood by the shiphandlers of each ship and VTS operators, it suggests the possibility that shiphandlers of many ships can manoeuvre their ships with the same feeling for degree of collision risk, which is extremely effective for enhancing overall safety.

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ABSTRACT

An analysis has been made of the risks involved with the transport of spent fuel elements on two transport routes from the Dodewaard nuclear power plant to Sellafield. At both routes, the B-type container is carried by road, rail and sea transport. At the present route, sea transport is carried out by a Channel Ferry. At the alternative route, sea transport is carried out by a special-purpose ship from Cherbourg to Barrow.

Due to International Law the safety of the transport is primarily defined by the characteristics of the B-container. For both routes, the risks are similar during road transport and train transport. Differences arise in the sea transport.

The main risk for the present route is a collision of the train-ferry at the Channel, resulting in sinking of the Ferry and salvage of the container. The main risk for the alternative route is beaching of the special purpose ship on the French or English coast. The B-container will remain intact. Salvage for the alternative route is much more difficult due to the unfavorable waterdepth and wave climate.

RISK ANALYSIS FOR THE TRANSPORT OF SPENT NUCLEAR FUEL ELEMENTS BETWEEN DODEWAARD EN SELLAFIELD

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1 INTRODUCTION

On behalf of the Dodewaard nuclear power plant a comparison has been made of two transport-routes with respect to the risks involved in the transport of spent fuel elements. The elements are transported in a so-called cask or B-type container between the power plant and the reconditioning plant at Sellafield, Great Britain. The present route and an alternative route have been compared. Both routes are identical for the Dutch part. For the present route, crossing the English channel is performed by a train-ferry.

The cask is further transported to Sellafield by train. At the alternative route, the fuel is transported by train to Cherbourg from where a ship especially built for the transport of casks (special-purpose ship) may transport the fuel to Barrow, a harbour close to Sellafield.
The aim of the analysis was to make a map of the dominant factors defining any differences in risk as an aid for decision makers.

2 BACKGROUND OF THE RISK INVOLVED IN THE TRANSPORT OF SPENT FUEL

Spent nuclear fuel has to be transported in a special container, also called cask, that is subject to very strict international rules. Under these rules, the container is called a B-type container. The radiation from the fuel will be minimal due to the shielding of the cask. A second function of the cask is to protect the fuel elements in case of an accident. The cask is designed to withstand certain collisions, a drop from a certain height, an immersion in water and a serious fire. Tests have been defined to make sure that the cask will survive the design conditions without any damage. The basis material for these tests is extensive.

The risk analysis was carried out in a number of steps. The first step was to estimate the probability of an accident during the transport of the cask. To this respect, literature data were compared and transformed into basic accident rates for both transport routes. For the second step, scenarios for damage to the container were considered. Since no B-container was ever damaged in reality, scenarios were based on a literature survey of tests and calculations.

A financial risk was included because of the salvage of a cask after the occurrence of an accident. A container with spent fuel will not be allowed to rest at the bottom of the sea after sinking of the transport vessel. From the very beginning of the analysis, it was clear that both routes differed in this respect.

3 RULES FOR A B-TYPE CONTAINER

International rules have been constructed by IAEA. Also national rules must be met. For the Dodewaard container, a Safety Report exists in which the compliance to these rules is reported. Governing for example the surface finish of the container with regard to decontamination, protection by means of shock absorbers, the dissipation of heat generated in the container and the segregation of the container from spaces open to the public, the rules make sure that transport risks are at a minimum. The cask is not allowed to leak after:

- a free drop test from a height of 9 m on a flat, horizontal and rigid surface. The cask must be hit on its weakest point.
- a free drop test from a height of 1 m on an iron bar, again at the weakest point of the container.
After submittance to the tests, the cask is not allowed to leak after a fire having a temperature of 800 degrees C for 30 minutes.

Suppose that in an accident more severe conditions are met. Does this mean that the cask totally fails and the spent fuel is fully released to the environment? This is certainly not the case. According to [Elder, 1981] a realistic scenario for a release as a result of a very serious collision and fire is:

- 30% release of noble gases such as Xe
- 0.03 to 0.04% release of radioactive elements such as Cs
- 0.25 to 2.5% release of the radioactive corrosion products that form at the fuel elements (this is called crud)

A second point is that in practice it is very difficult to arrive at more severe accident conditions than the tests conditions [Jefferson, 1985], [Blythe et al, 1987]. The velocity of a cask during a free drop tests may reach 50 km/h. Clearly, higher speeds are possible at accident conditions. However, a truly rigid surface cannot easily be accomplished. In the USA a container was dropped from a height of 600 m to a desert floor. The speed on impact was 375 km/h. The cask penetrated 1.3 m without substantial damage. According to [Jefferson, 1985] the 9 m free drop tests is comparable to an impact at 60 cm reinforced concrete at a speed of 140 km/h or 30 cm reinforced concrete at a speed of 190 km/h. This means that even for the scenario of the cask on a rail wagon hitting a reinforced concrete fly-over, it is uncertain that damage to the container will occur. Finally the results of full scale tests in England are mentioned. A railway locomotive was allowed to run full speed into a container for spent fuel. In conformity with the calculations the container was not damaged.

4 DESCRIPTION OF THE DODEWAARD CONTAINER

The geometry of the cask is shown in figure 1. In relation to its dimensions of 1.6 m by 3.1 m, the cask is extremely heavy and weighs 28 tons. The cask is constructed out of forged steel about 30 cm thick. The steel shields against gamma radiation and guarantees the structural strength of the cask in accident conditions.

The cavity inside the cask is filled with a Multi Element Bottle which holds 10 fuel elements. Water inside the cavity transports the generated heat to the cooling ribs. All entries to the cavity are sealed during transport by a system of grouped seals. Each sealing group consists of steel inserts and elastomer O-rings. Each group is leak tested. The shock absorbers at both end of the case are steel boxes filled with balsa wood. The absorbers have to be dismounted in order to gain access to the cavity.
5 DESCRIPTION OF THE TRANSPORT ROUTES

The transport is carried out under the responsibility of Nuclear Transport Limited (NTL). A Dutch speaking contact-person is present and in the possession of a list with all relevant telephone and telefax numbers including those of the authorities.

For the present route, the conditions are:

- road transport between the Dodewaard plant and KEMA Arnhem

The transport is carried out with a special trailer and truck combination. The distance travelled is about 22 km. At KEMA, the cask is hoisted to a rail wagon. For the present route, the cask stays at this wagon until Sellafield.

- rail transport between KEMA and the Roosendaal border station

The Dutch railways NS transport the cask in a special night train, consisting of 1 locomotive and 1 wagon only. The distance travelled is about 129 km.

- rail transport between the border and Dunkirk.

The Belgian railways and the French railways transport the cask further with any special trains nor ‘exclusive use’ conditions. There are in total 4 shunting yards in this part of the route. The distance travelled is about 273 km with transport taking place partly at night, partly during daytime.
- transport aboard a railway-ferry between Dunkirk and Dover.

At Dunkirk the wagon is loaded to the train-ferry 'NORD PAS DE CALAIS'. The distance travelled is about 65 km under 'exclusive use' conditions on a closed ferry deck. According to IMDG international rules the cask is segregated from other cargo.

- rail transport between Dover and Sellafield.

The transport is carried out by British rail over a distance of 675 km, partly by night, partly during daytime. The transport follows the same route as British nuclear transports.

In total the present route between Dodewaard and Sellafield takes 5 days. A distance of 1075 km is travelled by rail, and a distance of 65 km is travelled by means of the train-ferry.

For the alternative route, the part of the route until Antwerp is identical to the present route. However at the alternative route, rail transport is continued to Cherbourg. It is expected that handling at several shunting yards will take place. The distance travelled between Arnhem and Cherbourg is about 830 km.

At Cherbourg, the cask is lifted from the railway wagon to a special purpose ship. This may be regarded as an additional lifting operation compared to the present route. At the end of 1991 a Japanese cask dropped during lifting operations at Cherbourg. There were no radiological consequences. The probability of dropping a lift can not be neglected. However based on the characteristics of the cask, the probability of damage is negligible.

The special purpose vessel sails from Cherbourg by way of the Channel Entrance, the Scilly Isles and the Irish Sea to Barrow, a harbour close to Sellafield. At Barrow, the cask is lifted and carried by rail transport to Sellafield. The distance travelled is about 900 km. Because of the relatively slow speed of the vessel (about 13 knots), the sailing time is about 40 hours compared to 12 hours for the train ferry.

7 CONDITIONS DURING TRANSPORT

The Dutch part of both transport routes is identical. Urban areas with cities like Arnhem, Nymegen, Den Bosch, Tilburg, Breda and Roosendaal are along the route. For the remainder of the present route, cities like Antwerpen, Gent, Lille, Coventry, Birmingham, Wolverhampton, Stoke on Trent and Preston are along the route. Shunting in England takes place at Willesden Junction, a suburb close to London.
For the alternative route also large cities are along the route such as Antwerpen, Bruxelles, Paris, Caen en Cherbourg. Shunting yards are not known exactly. It was assumed that shunting takes place at St. Denis, an industrial suburb close to Paris.

At a first glance, the road and rail transport take place under similar conditions. Very detailed information is necessary to calculate the exact population density along the route. However, the Michelin guides for the Benelux, France and Great Britain are accurate sources of information to define the part of the route which passes close to cities of 10,000 inhabitants or more. For the present route with 1075 km rail transport, 23 % of the route is through urban area. For the alternative route with 830 km rail transport, the fraction of urban area is 18 %.

In order to analyze the traffic density along the route [Thomas Cooke 1991] was used. The risk related to traffic density is a function of the number of trains that pass the transport. It is governed by the probability that given a derailment of the transport, a (passenger) train will hit the cask.

The traffic density is also important with respect to the collective radiation dose to the public in passing trains. The traffic density could not be estimated accurately for both routes since it is very much dependant on the exact date and time of the passage of a particular part of the route. For the present route, the time schedule could be matched to the train tables. For the alternative route, an exact time schedule was not known. For both routes, busy parts with 2 to 4 trains per hour per direction were found to be present. Maximum traffic densities are in the London and Paris areas.

The conditions during sea transport differ considerably for the present and the alternative route. The train ferry at the present route crosses the busy Dover Strait at high speed. Ferry crews have a good local knowledge of the nautical conditions. In the Strait a traffic separation and guidance system is present, with radar-assistance and advice from the shore. The main stream consists of ships that largely vary in size and flag. Coasters and fishing vessels as well as supertankers destined for Rotterdam form part of the main stream. The flags are both of traditional seagoing nations such as Norway, Sweden, etc. as well as 'flags of convenience' such as from Liberia, Panama, Greece, etc. Dover Strait is not very wide. Sand-banks and shallows are present at both sides.

The alternative route by way of the entrance to the Channel and the Irish Sea has totally different characteristics. The width is larger, but the coast is rock strewn. The special purpose ship has to cross the main stream of shipping through the Channel and will join the West-going lane. The main stream of traffic is comparable to Dover Strait. Also here a traffic separation system is present, however it is expected to be less stringent. In order to reach the Irish Sea, the special purpose vessel has to pass the Scilly Isles. The Isles are infamous as a grave yard for ships.
Wave climate transport route for spent nuclear fuel
route A: Dunkirk - Dover
route B: Cherbourg - Barrow

Figure 2 Wave climate at the route
However, with modern (satellite) navigation the Scillies are not necessarily a problem. It is expected that the special purpose ship sails West of the Scillies into the Bristol Channel. It is not expected to use the route between the Isles and Cornwall. The Irish Sea has much less dense traffic conditions compared to the Channel.

The wave climate differs for the present route considerably from that of the alternative route, see figure 2. The alternative route is more exposed. It is expected that the relatively small special purpose vessel has more hindrance of the wave action than the large ferry. As the alternative route also takes longer, there is a larger probability on high waves when weather conditions worsen. For the alternative route, also the waterdepth is considerably larger compared to the present route. Both wave climate and waterdepth are important with respect to salvage of the cask after an accident. As will be discussed later, salvage is only possible when the weather is good and the sea is calm.

8 CHARACTERISTICS OF THE VESSELS

The main characteristics of the ferry are compared with those of a special purpose ship in table 1.

<table>
<thead>
<tr>
<th>Table 1 Main dimensions and characteristics of the transport vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ferry 'NORD PAS DE CALAIS'</strong></td>
</tr>
<tr>
<td>length</td>
</tr>
<tr>
<td>beam</td>
</tr>
<tr>
<td>draft</td>
</tr>
<tr>
<td>displacement</td>
</tr>
<tr>
<td>service speed</td>
</tr>
<tr>
<td>max speed</td>
</tr>
</tbody>
</table>

The ferry has 2 continuous decks of the Roll On Roll Off (RORO) type. The ship was built in 1987 and it has accommodation for 80 truck drivers. It is equipped with 2 high-effect rudders and 2 propellers. The ferry is very manoeuvrable. It also has an automatic system to limit the trim and heeling angle of the ship to 2.5 degrees while loading and unloading train wagons at a speed of 6 km/h. In order to limit rolling of the ship in waves, the ferry is equipped with anti-rolling fins. The ship sails with an unmanned machine room, all engines are controlled from the bridge. The ship has 3 radar systems. A satellite navigation system is not necessary for the Dunkirk-Dover trip. The ship is designed to carry wagons and trucks loaded with...
dangerous goods at special parts of the deck. These parts are equipped with fire fighting foam monitors. By means of doors on the after part of the train deck dangerous goods can be segregated from other cargo.

As an example of a special purpose ship 'PACIFIC PINTAIL' was chosen. The class of ships was especially built for the transport of spent nuclear fuel from Japan. Therefore the ships of the class satisfy the even more stringent rules of the Japanese Ministry of Transport. However, IAEA states that in the first place the safety of the system is based on the characteristics of the cask, rather than on characteristics of the transporting system. A special purpose ship of the 'PACIFIC' class has the following characteristics:

A the hull is strengthened against collisions
B the hull has a subdivision in combination with watertight bulkheads
C the ship has a double bottom
D the ship has a second anti-collision bulkhead at the bow
E the ship stays afloat with 2 cargo holds or machine rooms flooded
F the ship has 2 engines and 2 propellers
G the ship is equipped with both trusters.
H if necessary, a cargo hold can be flooded
I the ship has additional fire fighting equipment
J the ship has 4 separate navigation systems and satellite communication

The ferry 'NORD PAS DE CALAIS' does not possess the characteristics mentioned under A, D, E and H. Characteristic J is not necessary for the trip Dunkirk-Dover. A remark must be made in respect to the collision design. The hull design is based on a collision at a random point of the hull with the colliding ship being a 24,000 tons tanker at 15 knots. Such a tanker is relatively small because sizes of 80,000 to 250,000 tons may be regarded as normal. The cargo holds are cooled because of the heat generated by the maximum number of casks to be transported. Apparently the cooling is necessary in order to inspect the cask, not in order to preserve the integrity of the cask. It is not necessary to cool the ferry because of the small heat flux of the Dodewaard container. Therefore it was concluded that the ferry in use at the present route and the special purpose ship at the alternative route are equivalent except for the larger collision resistance of the special surface ship and the smaller stability margins of the ferry due to the RORO concept.

Special measures have been taken at the special purpose ship in order to combat any radiological incidents:

1 automatic logging of the ships position, speed and heading to the operations center at Barrow
2 24 hours availability of an emergency response team
3 availability of special tools and techniques needed for the salvage of a cask
4. a system to indicate the location of the ship if sunk and to monitor conditions in the cargo holds (radiation detectors)

For the ferry item 1 is not necessary since a traffic guidance system is in operation at the Dover Strait. With respect to item 2 and 3 it is mentioned that the special purpose ships are owned by Pacific Nuclear Transport Ltd, with British Nuclear Fuel Ltd holding 63% of the shares. The transport of the Dodewaard container is carried out by Nuclear Transport Ltd, again with British Nuclear Fuel a major shareholder. This means that in case of an incident at the ferry, the expertise under 2 and 3 will also be available. Since only 1 cask is transported at the 'NORD PAS DE CALAIS', item 4 is of minor importance.

9 BASIC ACCIDENT RATES

9.1 road accidents

Since the road transport is identical for both the present and the alternative route, road accidents do not influence the comparison. However, in order to be complete, road accidents were studied.

Basic accident rates can be found in literature. In [Appleton, 1988] an overview is present that is especially applicable to the situation of spent fuel. From the literature surveyed it was concluded that the basic accident rate is very dependent on whether all incidents are estimated or whether real accidents are counted given a certain severity. The accident rate is also very dependant on the type of road under consideration and, to a lesser extent, on the vehicle characteristics. From British, EEG and French studies it appeared that the probability of an accident for a cargo truck ranged between 0.8e-8 and 147e-8 accidents per truck km. A value of 2.1e-7 accidents per km is normally taken as reference level.

It is remarked that the basic accident rate is not the probability of an accident resulting in damage to the cask and the environment. The probability of damage, given an accident, still has to be taken into account.

9.2 rail accidents

There are not many published data on rail accidents. In the Dutch LPG-integral study an accident rate of 1.4e-7 per wagon km was found. However, the scenarios for a LPG accident and an accident with nuclear fuel differ considerably.

Therefore, an informal interview was held with the Dutch railways. From this interview the author draw the following conclusions. For the transport of nuclear fuel, only the number of high speed accidents is important, being only a small
fraction (about 2%) of all incidents. The majority of incidents (about 70%) takes place during shunting. Except in combination with a fire scenario, this type of accident does not threaten the integrity of a cask. At the interview, a basic high speed accident rate of 2.2e-8 per wagon km was mentioned. This preliminary accident rate was derived during studies for the new Betuwe railroad.

With respect to the conditions after an accident, the Dutch railways have a computer system that shows instantly what trains with dangerous goods are present on the railway network and what measures are to be taken in case of an emergency. All locomotives are equipped with radio. In case of an emergency, the information mentioned is also routinely sent to the authorities involved. The Dutch railways expected such a system to be present in Belgium, France and England as well.

A large amount of literature with regard to rail accidents and spent fuel transport has its origin in the US. The Dutch railways remarked that the basic accident rate from these studies may not be up to European standards. In Sandia Laboratories analysis, a US basic accident rate of 1.0e-6 per wagon km is mentioned. However, the situation in the US differs from Europe with respect to age of the equipment and speed. Also the US equipment has no buffers. An automatic coupling pierces the fronts of kettle wagons in case of a collision, resulting in an early fire.

In [Appleton, 1988] an review of the British situation was found. Because of studies for the nuclear power plant Sizewell B much analysis has been carried out. The basic accident rate for a derailment was found to be 3.0e-7 per wagon km. A basic accident rate of 5.2e-7 per wagonkm for a fire during rail transport could be derived by the combination of a given fire probability per year and a derailment frequency both given as a number per year and per wagonkm.

The survey of accident rates for rail transport gave a range of 0.2e-7 to 1e-6 per wagonkm. Since the majority of the rail transport at the present route takes place in England, the Sizewell B basic accident rate of 3e-7 per wagonkm was accepted. Not having found any data for the Belgian and French situation, this value was taken for all rail transport at both the present and the alternative route.

Again, the basic accident rate is not the probability of an accident resulting in damage to the cask and environment. The probability of damage, given an accident, still has to be taken into account.

9.3 accidents with sea transport

Ship losses and accidents at sea are found in literature on the basis of a number per shipyear, per shipkm or per ship journey over a given route [Appleton, 1988], [NMI, 1976], [Glansdorp, 1986]. On generally needs to assume some additional information in order to make a comparison possible. In the following text, the basic
Figure 3: Accidents at the French and English coast
(source: [Glansdorp, 1986])
Figure 4  Accidents in the Dover Straits surroundings (source: [Glansdorp,1986])
material is discussed. A presentation of the analysis in order to come to estimates for the basic accident rate is outside the scope of the paper. Conclusions from this material are presented at the end of this paragraph.

The basic accident rates are dependant on the area under consideration, the presence of a traffic separation and guidance scheme, and the dominant traffic situations. The loss rate for ships registered under 'flags of convenience' is significantly larger than for ships registered in a traditional seafaring country.

The Netherlands Maritime Institute [NMI, 1976] on behalf of KEMA has carried out a study with respect to the nautical risks involved with dumping radio-active waste in the Atlantic Ocean. Although dumping is not applicable, the accident analyses were highly applicable considering the route between Ymuiden and the Atlantic Ocean. The data origins from the Liverpool Underwriters Association over the period 1972-1977.

Much more recent data were found in [Glansdorp, 1986]. In this paper some results of traffic analysis by MARIN for the EEG Cost 301 project were found. The paper has been used to calculate an accident rate for Dover Strait as well as for the route around the Isles of Scilly. Also in this paper a collision probability in a crossing situation was found. It is a factor 7.5 higher than in encountering or overtaking situations. Although much arguments can be aroused with respect to the difference between ferries routinely crossing the main stream and an average number valid for Europe, the factor has been used in order to calculate a conservative value for the collision rate for the ferry crossing Dover Strait. The relevant accidents are shown in figure 3 and 4.

Norske Veritas have analyzed the safety of RORO shipping in [DNV, 1981]. It is remarked that the study is dated before the 'HERALD OF FREE ENTERPRISE' disaster, therefore conclusions are not influenced by this disaster. According to Veritas, accidents with RORO ships are relatively often serious and may result in total loss of the ship in a large number of cases. The percentage total loss as a result of collision is about 25 %, compared to 9 % for a general cargo ship and 15 % for a tanker. This is due to the stability characteristics of a RORO design, having a main cargo deck without watertight subdivisions. Because of the short time involved with capsizing, there may be a large loss of life. Also in [DNV, 1981] losses were recorded due to operational errors in harbour.

The Dutch 'Comittee on seagoing RORO ships', [Gerritsma 1987], has brought out a report in connection to the 'HERALD OF FREE ENTERPRISE' disaster. It was concluded that the direct cause of the disaster was the open cargo doors when the ship left Zeebrugge, in combination with a trim by the bow and a high velocity in relatively shallow water. The management on board and at the shore was criticized with respect to safety quality.
This means that, with management giving due attention to both causes of the accident, accident analysis shows that the ferry has a disadvantage over the special purpose vessel with regard to stability characteristics. This disadvantage is incorporated in the analysis by means of the fraction 'total loss' over 'all accidents'.

Based on the mentioned material, the following conclusion were drawn for the basic accident rate at sea:

Given the situation in Dover Strait, the largest risk for the ferry is a collision with crossing traffic. The collision rate is $3.8 \times 10^{-4}$ per trip, taking into account the already mentioned factor 7.5 for the effect of crossing compared to encounter or overtaking. There is a 25% probability that a collision will be a total loss for the ferry. It must be remarked that there is not a total loss of protection because of the cask characteristics.

The largest risk for the special purpose ship at the route Cherbourg-Barrow is beaching on the French or English coast. The probability of beaching is taken equal to that of a cargo ship, resulting in $1.6 \times 10^{-4}$ per trip with a 10% probability on a total loss. A remark must be made since most cargo ships only have 1 propeller, whereas the special purpose ship has 2 propellers. The probability of beaching is heavily defined by the occurrence of storm conditions or the occurrence of bad visibility or fog. It is expected that 2 propellers only gives a minor advantage to prevent beaching. The probability of beaching for the ferry is also estimated to be equal to that of a cargo ship: $7.5 \times 10^{-6}$ per trip. The difference with the special purpose ship arises due to the difference in sailing time and distance. There is a 10% probability on a total loss.

The probability of a fire is estimated to be equal for the ferry and the special purpose ship since most fires have their origin in the engine room. The probability of a fire is estimated at $2.0 \times 10^{-3}$ per shipyear. For the ferry there is a 6.5% probability on a total loss. Because of the design characteristics of the special purpose ship, a total loss as a result of a fire is estimated a factor 10 lower than for the ferry. Given the sailing time of both ships (about 2 hours for the ferry, about 40 hours for the special purpose ship) this results in a fire rate of $3.4 \times 10^{-7}$ per trip ($2.2 \times 10^{-8}$ total loss) for the ferry and $9.1 \times 10^{-6}$ per trip ($5.9 \times 10^{-8}$ total loss) for the special purpose ship.

All scenarios and the corresponding probabilities are given in figure 5. The probabilities can be checked to a certain extent given the service time of the ships. For the ferry at 4 years of operation with about 300 working days per year and 4 trips per day, no accidents have happened. Given 1 accident, the probability would have been $2.1 \times 10^{-4}$ per trip. The probability of an accident is thus most certainly lower than $4 \times 10^{-4}$ as calculated before. The estimation is a conservative one. In [Milne, 1987] it is reported that 6 special purpose vessels have a total service time of
Figure 5  Scale of risk for sea transport
43 ship years. Since 1 round trip takes about 18 weeks, 124 round trips have been made. Also here no accident has happened. Given 1 accident, the probability would have been $4e^{-3}$ per round trip Japan-Barrow-Japan. The probability on a part of this route has been calculated at $2e^{-4}$. A comparison with the service time does not result in a better estimate. However, the probability of beaching is estimated to be conservative. If necessary, better estimates would be possible making use of Bayesian update techniques.

10 ACCIDENTS AT WHICH THE CASK IS DAMAGED

In literature no cases have been found were a B-type container was damaged. This necessarily means that for the damage scenarios and their corresponding probability one must rely on damage calculations and tests.

In the USA extensive studies on the behavior of a cask have been carried out by Sandia Laboratories. In these studies use was made of calculations, computer simulations, scale models and lessons learned from general accidents. Given this material, it was used for much of the analysis under consideration. Also much basic material could be found in PATRANS 86.

10.1 truck accidents

Transverse collisions with fixed obstacles at high speed with a crush scenario were found to be the dominant scenario. The probability is a factor 300 lower than the basic accident rate. The probability of a fire with expected damage to the container was found to be a factor 1200 lower than the basic accident rate.

10.2 rail accidents

[Surrey,1984] was found to be an important source of information for the scenarios for rail accidents in Great Britain:

scenario A: A derailment of the wagon with the cask, followed by a direct hit on a fixed and non-compressible object such as a bridge of a fly-over. The probability on a collision with expected damage to the cask was estimated at $2.3e^{-10}$ per wagonkm, a factor 1200 lower than the basic rate.

scenario B: A derailment of the wagon with the cask followed by a collision with a train coming from the other side. The probability is estimated to be $2.3e^{-10}$ per wagonkm.

scenario C: A collision between the wagon with the cask and another train. From [Surrey,1984] a probability of $3e^{-10}$ to $1.5e^{-9}$ per wagon km can be derived. This probability is a factor 200 to 1000 lower than the basic accident rate.
scenario D: A severe fire with expected damage for the cask. The probability is estimated to be $5.2 \times 10^{-10}$ per wagonkm, a factor 600 lower than the basic accident rate.

Sandia Laboratories define crush, puncture and fire as the most important scenarios for a serious rail accident. All scenarios are estimated to be a factor lower than the basic accident rate:

<table>
<thead>
<tr>
<th>scenario</th>
<th>factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>static crush</td>
<td>17000</td>
</tr>
<tr>
<td>puncture</td>
<td>5300</td>
</tr>
<tr>
<td>fire</td>
<td>400</td>
</tr>
</tbody>
</table>

The fire scenario appears to be dominant. However, a combination of circumstances must occur with respect to a large amount of fuel, the absence of fire fighting equipment and unfavorable conditions for the penetration of fuel into the soil.

10.3 accidents at sea transport

With respect to incidents at sea it appears from [Appleton, 1988] that many incidents such as damage to the ship by a collision, engine failure, or even sinking of the ship does not threaten the integrity of a cask.

Sandia laboratories [Hutchison, 1987] has carried out a study to estimate the effect of collisions between ships or of other incidents on the integrity of a cask. To study the effect of collisions Sandia used Minorsky's method in combination with simulations for circumstances during the collision. Based on the simulations, the probability of hitting a cask given a collision with the cask placed at one fifth of the ships beam is estimated at $10^{-15}$ %. The probability of damage to the container, given a collision, is estimated at $5.9 \times 10^{-6}$ to $1.3 \times 10^{-5}$. Again this is an order of magnitude lower than the basic accident rate.

Stranding and fires have been studied by means of analysis of serious cases in practice reported by Sandia. Also the collision between 'OLAU BRITANNIA' and 'MONT LOUIS' at Zeebrugge was studied on the basis of information from [Ringot, 1987]. It is well known that the 'MONT LOUIS' carried 350 tons of uranium hexafluoride in 30 containers. The containers have a length of 3.6 m, a beam of 1.4 m and a weight of about 15 tons. As with a cask, the containers are proof against certain accident conditions.
From the basic material the following conclusions were drawn with respect to accident scenarios and salvage of the cask after an accident at sea.

- fighting a fire on a ship that is stranded at a remote place is problematical.
- strandings are mainly the result of extremely heavy weather and corresponding sea conditions. Weather predictions were not accurate or not timely enough.
- cargo that has a substantial strength is not or only minor damaged as a result of a serious stranding. The hull acts as a protection zone.
- coordination with respect to all authorities involved, as well as passing information to all parties concerned should not be taken lightly. Public interest in an accident with dangerous goods is very large.

Since strandings are weather dependant a capacity problem might occur because salvage companies are busy carrying out other jobs. The difficulties of carrying out a salvage job under Lloyd's open form were not studied. The actual monetary value of the cask and content is low. It must be salvaged because of the radiological characteristics of the content.

11 ALLOWABLE DOSES

In [Weber and Rasmussen, 1985] the biological consequences of radiation acting on human beings are described. A difference must be made between:

- early effects within a few weeks after a large dose higher than a threshold dose
- late effects, for which it is not known whether a threshold dose exist, resulting in a linear dose-effect relation as a working hypotheses.

A number of natural sources of radiation is always present, as well as doses from the medical use of radiation. Doses related to the transport of nuclear material can be calculated with the INTERTRAN computer code. This code is developed by IAEA and it is based on US and other models. The model calculates the radiation dose to transport personnel and members of the public in accident as well as non-accident conditions. The model has been reviewed by the IAEA [Appleton, 1988]. From this review it followed that the model has a number of shortcomings, especially with respect to the relation between basic accident rates and the scenarios for damage to the cask. Also to the opinion of the author the model is not very suitable in the case of transport by a ship. The model has not been used, however some data from literature were derived with the model.

Internationally accepted limiting doses have been established. A doses of 1 mSv per year has been established as a maximum individual dose. For personnel that professionally works with radiation a maximum doses of 50 mSv per year has been established. Because of future law the dose is expected to be limited to 20 mSv per year.
CONSEQUENCES OF AN ACCIDENT WITH A CASK

In [Surrey, 1984] the potential consequences are discussed. If a cask is damaged a fraction of the radiological content will be released into the environment. As a function of weather conditions, a plume will spread out. If a person is directly exposed to this plume, external radiation over the whole body occurs in combination with internal radiation from inhaled material. Part of the content of the plume will deposit on the land, roads and buildings. This will expose living beings and may result in contaminated food.

Therefore the consequences of a serious accident are dependant on the number of people involved, the weather conditions, the amount of contamination and the quality of measures taken in order to limit or counteract contamination. In [Surrey, 1984] an analysis of an accident with radiological consequences is discussed. It is especially relevant to the Dodewaard transport since it concerns a hypothetical train accident at the Willesden Junction shunt yard. A very serious collision has been assumed followed by a 2 hour fire at about 1000 degrees C. Radioactive material was estimated to be released to the environment for 1.5 hours. From calculations it was concluded that the threshold for early effects was not passed. Two cases of cancer above natural levels were expected. A probability of 1/1000 was estimated for the occurrence of 18 fatal cancers.

In [Surrey, 1984] also the opinion of CEP is discussed. CEP is an independent research institute in the US, which analyzed and criticized a number of research projects with regard to the transport of fuel. CEP found higher basic accident rates than SANDIA. According to CEP, accidents and especially serious accidents always are unique events that can be predicted only moderately. The economical effects of an accident are underestimated. This concerns for example the costs of people not being able to go to work, and the costs and possibility of cleaning large buildings that have air conditioning after an accident with a release into the air.

Not much data were found for the effects of radiation releases in a nautic environment after a shipping accident. In [Hutchison, 1987] data were found as part of the 'Subsea bed disposal program'. In this project a ship was supposed to transport highly radioactive waste in canisters. The waste was disposed of by dropping the canisters to the ocean floor. Sinking of the ship was regarded as a major risk. Over a period of 25 years the effects of released radiation were considered. The highest individual dose would occur if the ship sunk in coastal waters without any salvage. The individual dose would be about 7 mSV per year, about 7 times the average natural amount of radiation. As a second source of information, the effects were compared with known Sellafield releases over the period 1960-1985. Given the release of a damaged cask as quoted in [Surrey, 1984], the release is minor compared to Sellafield releases, also when compared to the considerably reduced releases after 1975.
It was concluded that from a radiological point of view a sunken and damaged cask for fuel transport does not present an acute threat to the environment. However, because of the radioactive content, it cannot be left uncontrolled at the bottom of the sea. It must be salvaged.

13 RADIATION DOSE IN THE NON-ACCIDENT SITUATION

Based on literature data the radiation dose in the non-accident situation can be estimated. Partly the doses mentioned in literature are calculated with INTERTRAN, for example the dose given to the public. Doses to truck drivers, railway personnel and the personnel on board are measured with dosimeters.

The largest doses are received by those persons that are actively involved in the handling of the casks. The doses are lower than the limiting doses. The dose to the public is negligible.

14 CONCLUSIONS

The probability of an accident with road and rail transport of spent fuel between Dodewaard en Sellafield can be estimated from literature. The characteristics of both routes are similar for this type of transport. In both cases large cities are along the route.

The safety of the transport is defined by the characteristics of the cask. The cask complies with very strightly IAEA safety rules. No accidents have been found where the cask with spent fuel was damaged. Given the characteristics of the cask it can be concluded from calculations and tests that the probability of an accident with a damaged cask must be orders of magnitude smaller than the basic accident rates.

The largest differences with respect to risk for both routes occur with the sea transport. The largest risk when transport is carried out with the train-ferry is a collision in Dover Strait with crossing traffic. The ferry has to be salvaged because of hindrance to the traffic. The largest risk when transport is carried out with a special purpose vessel is a stranding of the vessel on the French or English coast.

The cask is not expected to be damaged at either the collision or the stranding. The ships hull will act as a protection zone. However, the cask must be salvaged because of the highly radioactive contents. The cask does not immediately threaten the environment. Especially for the special purpose vessel it is expected that the salvage is difficult because of the environmental conditions. Therefore preference is given to the present route instead of the alternative route.

The doses because of radiation from the cask in the non-accident situation are well below the international limits. The dose to the public is negligible.
Table 1 Overview of the difference in both routes for the transport of spent fuel

<table>
<thead>
<tr>
<th>aspect</th>
<th>present route A</th>
<th>alternative route B</th>
</tr>
</thead>
<tbody>
<tr>
<td>road transport</td>
<td>- identical</td>
<td>- identical</td>
</tr>
<tr>
<td>rail transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- total length</td>
<td>1075 km</td>
<td>830 km</td>
</tr>
<tr>
<td>- duration</td>
<td>both about 5 days</td>
<td>18 %</td>
</tr>
<tr>
<td>- fraction of urban area</td>
<td>23 %</td>
<td>18 %</td>
</tr>
<tr>
<td>- intensity train traffic</td>
<td>comparable</td>
<td>comparable</td>
</tr>
<tr>
<td>- scenarios with largest risk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(fire, derailment, derailment followed by collision)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Dutch part</td>
<td>identical</td>
<td></td>
</tr>
<tr>
<td>sea transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- vessel</td>
<td>train-ferry</td>
<td>special purpose ship</td>
</tr>
<tr>
<td>- length</td>
<td>65 km</td>
<td>900 km</td>
</tr>
<tr>
<td>- duration</td>
<td>2 hours</td>
<td>40 hours</td>
</tr>
<tr>
<td>- number of containers</td>
<td>1</td>
<td>several</td>
</tr>
<tr>
<td>- traffic guidance system</td>
<td>yes</td>
<td>moderate</td>
</tr>
<tr>
<td>- traffic situation</td>
<td>crossing traffic</td>
<td>join and pass next to</td>
</tr>
<tr>
<td></td>
<td>Dover Strait</td>
<td>Scilly Isles</td>
</tr>
<tr>
<td>- wave climate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- scenarios with largest risk</td>
<td>collision</td>
<td>stranding</td>
</tr>
<tr>
<td>- probability per trip</td>
<td>ca 4e-4</td>
<td>ca 2e-4</td>
</tr>
<tr>
<td>- waterdepth</td>
<td>20-50 m</td>
<td>10-110 m</td>
</tr>
<tr>
<td>- salvage conditions after an accident</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>significantly worse at route B</td>
<td></td>
</tr>
</tbody>
</table>
LITERATURE


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RISK ANALYSIS AND RISK COMMUNICATION IN THE TRANSPORT OF DANGEROUS GOODS

by

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RISK ANALYSIS AND RISK COMMUNICATION IN THE TRANSPORT OF DANGEROUS GOODS

1. Initial situation

In the Federal Republic of Germany, safety policies in the dangerous goods transport sector are increasingly being reoriented towards the problems revealed in risk analyses. This was prompted by the 1987 tanker accidents in the towns of Herborn and Schonach triggering discussions about the risks of dangerous goods and the routes to be assigned to particularly high-risk goods. New questions and problems continue to arise from the steady increase in traffic and goods traffic volumes, also in respect of the policies relating to dangerous goods transport. Conventional strategies are no real solution, in most cases they can only be used to respond to a situation. The aim is to design an anticipatory risk management strategy--conceived as a reflective learning system--to improve and extend the problem solution possibilities.

Undertaking a risk analysis of dangerous goods transport was considered by a project group of the Federal Highway Research In-

1) The paper is based on the report by H. Baum et al, Forschungsprogramm "Sicherheit in der Gefahrgutbeförderung", Bergisch Gladbach, 1992, pp. 13-.
stitute (BASt) as a first step towards and central instrument of a comprehensive risk management system. Based on this proposal, BASt was commissioned by the Federal Minister of Transport to have an analysis of the risks connected with dangerous goods carried out on the railway, inland waterway and road transport sectors.

2. Requirements for a risk analysis on dangerous goods transport

The present and, even more so, the changing goods transport conditions in Europe will be taken into consideration in developing and undertaking the risk analysis. The excessive loads on the existing transport routes associated with the rapid increase in goods transport volumes will give cause to radical structural changes in the transport markets. This will also result in a constant change in the risks involved with the carriage of dangerous goods.

Commissioning a differentiated, costly and time consuming risk analysis would not much serve the purpose in this context. Though, in the ideal case, it might be able to precisely and comprehensively describe the present state of affairs, it would in view of the dynamics of the transport markets soon have lost most of its value, excepting perhaps its methodological worth. For that reason the risk analysis has been so conceived as to be able to not only simulate structural changes in the transport markets...
and the flow of goods but also, by means of altering parameters, hypothesized developments.

It is important to ensure that the alternatives for action be represented in their anticipated potential effects on transportation. Due to the impending near-crisis situation of goods transport, it is less and less possible to implement the measures of those responsible for decisions without prior evaluation (e.g. assessing the consequences of modern technologies). Interacting with other systems--especially the economy, employment system and other national economies--and becoming increasingly complicated, the goods transport system is in a situation that could be likened to a high-risk system to the extent that system errors are followed by such high costs for the society that empirical learning from system errors alone cannot (no longer) be accepted. They must be excluded beforehand, if possible.

In this context, BAST's project group considered it as appropriate to base the risk analysis on representative transport chains and not on a comparison of transport modes. Comparing transport modes suggests the idea of searching for alternative transport possibilities, but the development of the transport markets and the organisation of goods transport in the future will require a greater extent of cooperation between different transport modes and combination of transport routes than has been the case
The risk analysis should therefore meet the following requirements:

- Assessment of the risks involved in the transport of dangerous goods based on transport and accident statistics.
- Description of the risks involved and the weak points of the carriage of dangerous goods.
- Provision of scientifically sound analysis data for the planning of measures to reduce the transport risks, and support of the efficiency control of such measures.

3. Description of risk analysis

The aims mentioned before are to be achieved by means of a risk analysis undertaken in three steps. The individual elements of the risk analysis consist of:

- a risk analysis based on accident statistics;
- an analysis of weak points; and
- a computer-aided system model to be developed based on the steps above.

3.1 Risk analysis based on accident statistics
Up to the present time, a methodically sound description of the accident risk involved in the transport of dangerous goods has not been available in the Federal Republic of Germany. A knowledge of this risk is, however, required in order to base concepts for the safety of dangerous goods transport on a better empirical foundation and integrate safety aspects more clearly into the calculation of operational and logistics decisions of transport companies, consignors, and recipients of dangerous goods than has been done hitherto.

Based on known accident and transport statistics, the risk of the carriage of dangerous goods should be assessed to obtain a first systematically derived survey of the risks involved with dangerous goods for the typical transport chains. A transport chain may consist of split and unsplit transport by various transport modes (road, railway and inland waterway) and also include goods handling and storage, if required. Risk areas in the transport chain have to be identified and rated with respect to their importance (accident frequency, accident severity).

The elements of which transport chains are composed have to be defined and determined based on the flow of goods of typical transport chains. Cross-border goods transport also needs to be considered. By means of mathematical and statistical methods, the transport risk involved in the elements and the transport chains are then
to be determined and described in terms of accident rates and accident cost rates. Where data are lacking (e.g. transport volumes), they should be assessed by means of suitable methods (e.g. interviews) to obtain an idea of their magnitude.

Foreign methods to determine the risk connected with the carriage of dangerous goods should also be taken into account, both empirically and with respect to method.

3.2 Analysis of weak points

Identifying and describing the risks arising from dangerous goods is not enough to comprehensively disclose the factors causing the risk. A systematic analysis of the weak points of transport chains will help finding further conditions likely to give rise to risks.

A systematic identification of risk factors, including those involved with cross-border transport, should be possible based on the known methods of analyzing weak points (fault tree analysis, event tree analysis, failure mode and effects analysis).

The objective here is developing hypotheses on the frequency of events and on the relevance of the risk factors therewith. Their empirical foundation and confirmation is seen as the permanent task of a future risk
management system which will be developed to complement the risk analysis. The analysis of weak points together with the procedural strategies to be worked out will enable systematic surveys of the empirical knowledge on weak points to be made. These surveys will mainly concentrate on the persons employed in the transport sector (drivers and accompanying personnel, storage and handling personnel, consignors, carriers, recipients, officers for the prevention of risk, controlling officials, experts and certification services). Their knowledge on dangerous situations, risk conditions, accidents and near-misses will be systematically collected and evaluated by means of the risk management system. This method is expected to lead to an empirically sound evaluation of the hypotheses on system risks determined in the analysis of weak points.

3.3 System model

A risk-relevant representation of dangerous goods transport within the context of a computer-aided system model enables the simulation of a great variety of risk scenarios. This will not only yield empirically well-founded aids for transport policies but also for the management strategies of the transport industry as well as its decisions on the use of dangerous goods transport. A theoretically oriented risk analysis system model is expected to serve the following purpose:
- simulating alternative system schemes by changing input parameters (e.g. variation of transport quantities, use of alternative means of transport or alternative containments and change in economic boundary conditions) and illustrating the changes in risk conditions at the same time;
- providing assistance for the routing tasks;
- modelling the specific risks arising from individual dangerous goods in the transport chain;
- modelling the risks connected with partial dangerous goods transport areas, e.g. regional transport chains; and
- assessing the entire risk potential of a transport chain.

Based on the individual projects described above, the model should be developed and, if possible, harmonized with foreign and domestic projects for the determination of the risks involved in dangerous goods transport. In its final development and implementation phase, the system model should be incorporated into the IT networks of the goods transport markets, which are currently in the process of development. By means of these networks, the transport processes within a transport chain can be analyzed in advance, surveyed on a continuous basis and controlled. Within the scope of the PROMETHEUS and DRIVE projects and the ATT programme, which is a successor
of DRIVE, research efforts are concentrating on the development of integrated computer-aided strategies of coping with traffic control and logistics tasks (Both, Davidson and Möller, 1991, pp. 1139 --; Theis, 1988, pp. 100 --). Integrating the results of the two first mentioned research programmes above and placing greater emphasis on state interests in the use of information technologies, a research strategy for systems control of goods traffic is proposed in the study "Goods vehicle control and supervision system 2000 (NSÜ 2000)" (Both, Wörner und Gerner, 1991).

4. Strategies of risk reduction

Apart from the determination and description of the risks, information on justifiable risks is also often the objective of a risk analysis in order to provide orientation aids for risk reduction policies and target values for the planning of countermeasures. Although it is still widely accepted that justifiable risks are quantities to be determined in the political sphere, there have always also been analytical attempts to find answers to this question.

Rowe (1983, p. 20) names the approaches below as the four most important methods of analysis:

- revealed preferences approach;
- implied preferences approach
  (indirectly derived from social conventions);
- expressed preferences approach
  (derived from interviews on risks);

and

- cost-benefit analysis.

All these methods attempt translating people's values into optimal solutions to politically contested acceptance problems, thus representing the connecting link between scientific analysis and policy decision.

The theoretical details of these planning procedures need not be mentioned here; the reader can be referred to the relevant literature (Rowe, 1983). As valuable as these planning approaches may be for a clarification of problem structures, a satisfactory solution to the problem of evaluating industrial risks cannot be expected from them, as shown by the controversies over their analytical performance ability (cf. Fishoff et al, 1983, pp. 60-; Wynne, 1983, pp. 157-; Perrow 1989, pp. 35-; McGinty and Atherley, 1977; Rowe, 1983, pp. 28-).

The same applies to the results of these methods, which by themselves are not a means of reaching a consensus in the population, namely the consensus on the risks faced in an industrial society that could be used as a basis of policies in our democracies (cf. Beck, 1986; Conrad, 1983,
Compared with the socio-economic costs of all road accidents, the accident risk of tankers carrying dangerous goods is a comparatively marginal safety problem. According to Krupp (1988, p. 202), only 0.12% of the overall socio-economic costs of road accidents in the first half of the eighties were incurred by tanker accidents involving the leakage of dangerous substances.

However, the great public interest and the fierce discussions about the risks connected with dangerous goods transport after the Herborn accident (cf. Krupp, 1988, p. 210; Klein, 1987, p. 9) must be taken into consideration despite the above finding. As a consequence of the difference between the research findings on the magnitude of the risk involved and the orientation aids for policy and action they imply on the one hand and the public attention and assessment of such risks on the other, further means of mediation between industrial risks, their scientific analysis and evaluation on the one hand and risk policies on the other are obviously required.

5. From risk management to risk communication

5.1 Risk communication as additional risk policy component
Drawing on the conditions of a "risk society" (Beck), there have been many attempts to explain the new element in risk policy. Despite the great variety of explanation attempts, from the reproach of irrationality (Birkhofer and Köberlein, 1987, pp. 170-) to exaggerations, such as "social" rationality outside the realm of science (Perrow, 1989, pp. 375-), all of them confirm that the situation has changed and that it is required to react to it in the search for solutions to risk problems.

A third component must be (and has indeed already been) added to the bipolarity of science and politics, namely risk communication with all the population groups concerned. Whether a risk society can turn into a "learning society" (Langenbucher, 1991, p. 528), remains an open question. To be sure, politicians do respond to changed conditions. Environmental policies bear this out. The increased requirements for policy action on the sides of the decision makers are mainly the result of the heightened environmental awareness of the population (Langenbucher, 1991, p. 529). When counselling politicians on the issue of dangerous goods transport, the new conditions should be kept in mind. The dangerous goods transport system should accordingly be linked with a learning risk prevention system. In that case a continuous exchange between participants and the social groups concerned would result on the transport issue and, in the ideal case, even control over the problem.
5.2 Development of structures for a linked IT network incorporating the parties concerned

Since, as explained by Conrad (1983, p. 234), risk and safety policies on the dangerous goods transport sector can only be successfully implemented if decision making bodies remain trustworthy, their legitimacy acknowledged and an acceptable consensus is reached, these are the very objectives aimed for by organising policies in the manner described. According to Conrad (1983, pp. 234-), the following conditions have to be satisfied in order to orientate policies toward these aims:

- Abandoning the focus on single risk problems in research, planning and policy and dealing with the organisation of control and regulation processes instead.
- Inclusion of the groups affected by the risk as a fair-procedure criterion. This also requires
- Public information and discussion on dangerous technologies prior to investments and other basic decisions; and
- Incorporation of a greater number of cooperative elements into the development of objectives and the decision making process in order that a greater number of consensus solutions may be the result of the bureaucratic and
technocratic procedures undertaken to arrive at a solution.

Information deficits in the transport sector, about the systematic integration of the public into the decision making process and about the continuous analysis of new technology developments in the transport sector still stymie an appropriate approach to the risks connected with the transport of dangerous goods. Fig. 1, Annex 1, is an illustration of how risk communication could be structured and organised.

Risk analysis as continuous testing instrument and empirically sound early warning system in the dangerous goods sector represents the central scientific component of risk communication, as outlined in Chapter 3 above. In view of the increasing international linkage of transport markets, the data required for analysis should also increasingly be collected from international sources. In addition, procedures to ensure information on new dangerous goods and their transport routes should be worked out in order to be able to analyse and assess the new risks resulting. The same applies to new transport technologies.

In addition to the analysis, the international exchange of research reports, and analysis of media reports on dangerous goods transport, further instruments need to be established in order to enable scientific contributions to the risk communication to be made. In this way scientists
could contribute important information benefiting the other participants in the risk communication. The information of the relevant bodies in politics and the society is of crucial importance for the mutual learning process, as outlined in Fig. 1, Annex 1.

5.3 Periodic status reports on the state of affairs in the dangerous goods transport sector

Periodic status reports on the state of affairs in the dangerous goods transport sector should be prepared and published as summary statements compiling the information about the risks connected with the carriage of dangerous goods collected on a continuous basis. Such reports would provide important background data not only for the discussions in the policy and decision making processes but also for the public actively interested in risk policy issues. The appropriate editor of these reports would be the Advisory Committee on the Transport of Dangerous Goods with the Federal Ministry of Transport.

Discussions of the reports in the media and the opinions of the organisations addressed--industrial and trade associations, political bodies and activists--would be effective instruments of public participation in the formulation of dangerous goods transport risk and safety policies. To a certain extent, the reports of the Council
of Experts on the overall development of the economy and the discussions regularly triggered by them can be considered as examples of the formulation of objectives of this nature, prior to parliamentary action. On this basis, where scientific analysis, public discussion and evaluation could be interlinked, parliament and administration would be in a better position to implement policies in harmony with the objectives of society.

In this way, the transport and shipping industry would receive more reliable information about the public acceptance of the transport of dangerous goods and politics, economy and society would be enabled to harmonize their interests in dangerous goods transport on a continuous basis. In all, this would result in placing the transport and shipping industry on a far more reliable and stable footing than hitherto for undertaking the carriage of dangerous goods.
Fig. 1: Risk Communication in the Transport of Dangerous Goods
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OPERATION
EXPERIENCES IN APPLICATION OF THE TCT TECHNIQUE TO PEDESTRIAN SAFETY EVALUATION

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Abstract

Very high accident rates in Poland are still associated with very high risk exposure of pedestrians. They are involved in almost 60% of reported accidents. When considering various possibilities of improvement of pedestrian safety, various research methods were taken into consideration, including known traffic conflict technique. Results of empirical measurements have been used not only for qualitative evaluation of accidents factors, but also for validation of the TCT usefulness in predicting of pedestrian accidents. In this study poor correlation was obtained between the recorded numbers of accidents and traffic conflicts and therefore the range of analyses was broadened to employ also relationships between the relative rates of accidents and conflicts.

Starting from the assumption of different pedestrian accident risk caused by various movements vehicles, numeric weights for various conflict types were estimated. This estimation have shown an essential influence of the level of traffic conflict detection by seperately instructed survey groups.

Introduction

Pedestrians are the group of road users with a very high accident risk in Poland. Despite of a certain decrease of the percentage of accidents involving pedestrians they still are involved in almost 60% of reported accidents, in which they are the most wronged victims. Almost every third accident involving pedestrians occurs in places provided for pedestrian crossings. With such situation, there is great potential for countermeasures to reduce number of accidents at pedestrian crossings.

The majority of former accident studies and papers, pointing out very high pedestrian accident risk, are very general and do not contribute to the identification of accident factors. In order to increase an efficiency of safety improvement measures employed to improve unsatisfied pedestrian safety, in-depth the why and the wherefore studies are required. Efficiency of such studies can be increased by applying, as a measure of an accident risk, not only the number of accidents (or ratios which are combination of accident numbers), but also other measures like for example: traffic conflicts, critical events or traffic flow parameters. This is especially required in places, where justifiable are suppositions regarding a quality of accident data, or simply organized systematic
accident data collection does not exist. At the same time, not meaningless are such faults of the incorporation of accident number in the safety evaluation, as fact that at most location accidents occur infrequently and sporadically, so a long time period is needed (usually 3 years or more) to collect enough accident data to conduct a useful diagnostic analysis and also low quality of data mentioned earlier.

Using of traffic conflicts as surrogate measures of pedestrian safety, required earlier validation of a thesis about an existence of relationships between the number of some pedestrian/vehicle conflicts types and the number of corresponding accident types. Published results of former studies in this area are not univocal.

Besides works providing proof that a relationships exist between pedestrian conflicts and the corresponding accidents types, research results neglecting such relationship can be found too. In such situation the authors have undertaken own validation studies with the aim of practical application including also specificity of traffic conditions in Poland. Within the first stage, the research included signalized pedestrian crossing surveys.

Field surveys and the method used

In empirical traffic surveys the TCT method described in Erke & Gstalter (1985), Parker & Zegeeer (1989), Rieser (1991) has been used. This method was adopted to conflicting movements at signalized pedestrian crossings.

A traffic conflict is here defined as situation indicating an interaction between pedestrian(s) and a driver, if at least one of them causes the other users to make an evasive maneuver to avoid a collision. The evasive maneuver of the driver include breaking, changing a vehicle path, and acceleration to reach a potential collision point before arrival of a pedestrian. The evasive manoeuvres of a pedestrian include stopping, moving back, acceleration to running or jump aside. In traffic surveys, reactions of the road users to traffic signal indications have not been included.

Traffic conflicts were recorded by the trained observers, observing evasive traffic manoeuvres with simultaneous registration of the traffic conflict type and its weight factor. Four types of conflicts shown in Fig. 1 have been distinguished.

Observers recorded also additional data including an indication of traffic signals in the conflict time and location of conflict point within the pedestrian crossing area.

The surveys were conducted at 62 signalized pedestrian crossings in Krakow. At all sites geometric layouts and traffic control solutions have not been changed for the last 7 years, i.e. the time period from which accident data were taken into account. Traffic conflicts were recorded in May and June within the periods of 15 hours at each site.
Analysis of results

General characteristics of the pedestrian accident risk caused by various streams of a vehicular traffic at the studied sites is shown in Fig. 1. Relatively low percentage ratio of the pedestrian accidents with turning vehicles movement, besides an allowed conflict (i.e. movements in the same phase) should be pointed out. Low speed of turning vehicles together with a presence of pedestrians usually expected by drivers, undoubtly have favoured traffic safety.

Fig. 1. Distribution of accidents and traffic conflicts in a sample

Unfortunately the predominant is a group of accidents involving pedestrians and through vehicles (running into), despite of traffic segregation in time, due to a traffic signal operation.

The structure of the 547 recorded conflicts at 50 sites is shown in Fig. 1. This figure gives an initial evaluation of a consistency between numbers of various types of accidents and numbers of recorded various conflict types. In the collected data, the noticable lack of the consistency of the percentage distributions of accident types and traffic conflict types was found. It results mainly from the differentiation of a probability of transition from a conflict situation to a given accident type. A hypothesis can be formulated that allowed by traffic signals indication, simultaneous presence of pedestrians and vehicles in the areas of pedestrian crossings, leads to a more controlled relative movements of road users, than in case of total traffic segregation, which also affects the conflict weigh.
In case of the pedestrian/turning-vehicles conflicts only a small part of them involves conflicts at full segregation of traffic. It can be also seen from Fig. 1 that in case of conflicts of type 2 and type 3 they were in 70% caused by pedestrians, i.e. by violating the red light.

To validate a truthfulness of the thesis that strict statistically significant relationship exists between a number of conflicts recorded within 15 hours and a number of accident of the corresponding type from the period of 7 years has been investigated. The obtained relationship for sites illustrates Fig. 2.

Fig. 2. Relationship between the recorded accidents and the corresponding traffic conflicts.

For the considered sample regression analysis has not shown, an existence of a significant relationship $A_p$ and $C_p$, as for the linear model $R^2 = 4.6\%$ was obtained. Looking for possible sources of such result, i.e. lack of functional relationship between $A_p$ and $C_p$ in the studied sample, two explanations were considered:

- possibility of various levels of traffic conflicts detection by the observers (in surveys two separately trained groups of observers were involved),
- differentiation of a level of pedestrian accident risk by vehicles of various movements involving weights of conflicts.

Investigating deeper the first possible explanation mentioned above
the relationships between $A_p$ and $C_p$ were analysed separately for groups of sites surveyed by the two teams. For the first team (12 sites) a determination power of the studied relationship, given by the formula:

$$A_p = 0.037 C_p + 1.19$$  \hspace{2cm} (1)

was characterized by $R^2 = 0.214$

and for the second team (50 sites) was very low - characterized by $R^2 = 0.05$

Further analysis of sites surveyed by the second team focussed on a possibility of increasing the determination power of the relationship $A_p(C_p)$, by implementing weights for various types of conflicts including different levels of probability of transition from a conflict to an accident. A numerical values of weights were determined according to criterion of consistency of accident distribution and distribution of weightened numbers of the corresponding conflicts.

For the sample of 50 sites surveyed by the second team the following values of conflict weights were obtained:

- type 1 - 1.00
- type 2 - 7.00
- type 3 - 5.96
- type 4 - 2.19

By including the determined weights in the regression analysis the following linear relationship between the number of accidents and weighted number of conflicts $C_w$ was obtained (Fig.3)

$$A_p = 0.031 C_w + 2.83$$  \hspace{2cm} (2)

for which $R^2 = 0.12$ and the standard deviation $S_c = 3.01$

The obtained result shows an essential qualitative change in the investigated relationship in relation to (1) but the relationship (2) is still very weak and does not give a background for accident prediction on the basis of the number of traffic conflicts.

The assumed manner of the weights determination requires their local calibration what additionally limits the possible practical application of the TCT. It has also occurred that various levels of traffic conflict detection assumed by the two surveyed teams can affect the values of the weights. It can be also seen on the basis of weights obtained for the first team:

- type 1 - 1.0
- type 2 - 2.1
- type 3 - 2.8
- type 4 - 2.9

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Fig. 3. Relationship between the weighted number of conflicts and the number of corresponding accidents.

In such situation attempts were focussed on improvements of the power of relationship between accidents and traffic conflicts by taking also into account pedestrian and traffic volumes existing in the period of conflict surveys and including relative indicators determined as follows:

\[ C_{w} = C_{w} \times 10^{4} / \sqrt{q_{p} \times q_{v}} \]  \hspace{1cm} (3)

\[ C_{r2} = C_{w} \times 10^{2} / \sqrt{q_{p} \times q_{v}} \]  \hspace{1cm} (4)

where:
- \( C_{r1} \) - number of the recorded conflicts including weights of the conflict types.
- \( q_{p}, q_{v} \) - pedestrian and vehicular traffic volumes respectively, in the conflict registration period.

Results of comparison of the relative indicators described by formulae (3) and (4) with the accident numbers for 20 study sites, where simultaneously with the registration of conflicts traffic counts were conducted, are shown in Fig.4.
Fig. 4. Failed relationship between indicators $C_{r1}$, $C_{r2}$ and the number of corresponding accidents.

Regression analyses have also indicated that significant relationships between the indicators $C_{r1}$, $C_{r2}$ and the number of accidents $A_p$ do not exist.

Apart from the possible sources of this surprising research results (for example a small size of the sample, decreasing role of
the traffic volume for certain types of conflicts, by the segregation of traffic forced by traffic signal indications a new argument has been found questioning a usefulness of traffic conflicts in the accident prediction at pedestrian crossings.

Concluding remarks

The results of the conducted analyses have shown that the relationship between the accidents and traffic conflicts obtained for the analysed sample made the initial assumptions rather doubtful and questioned a potential usefulness of the TCT in accident prediction at the pedestrian crossings. Certain improvement in the power of relationship between the number of pedestrian accidents and conflicts can be obtained, by involving weights for particular types of conflicts. However values of these weights are not universal, and the weights determination requires a calibration for local conditions (city, region).

Including the additional variables in the model of accident estimation, as traffic volumes of the conflicting pedestrian and vehicular streams, has not brought any evident results in relation to the relationships power.

Critical remarks given above do not forejudge about a rejection of the TCT in the pedestrian safety analysis. Further, more comprehensive studies are required in this area. The TCT occurred very useful in the qualitative analysis of the accident causes.

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DONT’T WAIT FOR ACCIDENTS
POSSIBILITIES TO ASSESS RISK IN TRAFFIC BY APPLYING THE
"WIENER FAHRPROBE"

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In Vienna during more than 10 years of research work a
special traffic behaviour observation method has been
developed, evaluated and applied by RISSEr et al. in the
frame of many different traffic safety projects.

Car-drivers are accompanied by two observers who register
not only errors in behaviour of drivers but also their
communication and interaction with other road users.

Malfunction of communication and interaction are judged as
main sources for problems for danger in traffic. E.g. if
they lead to a bad traffic climate feelings of discomfort,
anger and frustration will prevent cooperative actions of
road users. Being able to recognize such negative or
dangerous interaction patterns in time it seems to be easier
to protect road users – most often the "unprotected" ones –
from getting involved in accidents.

This contribution gives an impression about theory and
practice of the observation method and show results of
different studies, where the method called "Wiener Fahrpro-
be" has been applied. Furthermore it will show how the
method resp. it's results can be used in the frame of the
European traffic (safety) research projects "PROMETHEUS" and
"DRIVE". Before application of new RTI-systems where no
accident data exist till now it seems to be important to
have a sophisticated social-psychological method for testing
the behaviour and interaction of road users in connection
with these systems resp. for testing if the systems are
socially compatible.

Introduction: Future Traffic

In the not so very far future man will be involved in a lot
of changes in the traffic-system in Europe. Within the frame
of the EUREKA- and EC-projects PROMETHEUS and DRIVE, e.g.,
we have to get prepared for the implementation of new RTI-
systems (Road and Traffic Information systems), where high
tech shall provide for safer and smoother traffic.

The integration of vehicle and traffic control is the
essential means to improve efficiency and safety in road

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traffic. In PROMETHEUS this will be done on three levels of control:

- travel and transport management (trip planning and reaction to actual traffic situation for better use of the available infrastructure)
- traffic flow harmonization (the cooperation of groups of drivers in local traffic for safer and smoother traffic flow)
- safe driving (autonomous vehicle control for safer driving with less mental load on the driver)

But the last two letters of the acronym PROMETHEUS which stand for "Unprecedented Safety" lead to some big problems which have to be solved to make PROMETHEUS aims become reality:

- in regard to the new technologies there exist no accident data at all till now
- nobody really knows how road users will interact with the new systems
- nobody knows if traffic participants, mainly the motorists will accept these innovations in a way the producers hope they will do.

Moreover man (mainly drivers of motor vehicles) will be confronted with three groups of measurements which will lead to driving conditions that are very different from today (PRO-GEN 1990):

- systems will intervene in the operation of the vehicle, e.g., by controlling the relative speed and distance between vehicles in the same lane (= "Autonomous Intelligent Cruise Control")
- there will be a lot of warning functions regarding different traffic conditions (e.g. "Collision Avoidance" systems investigate driving strategies for collision avoidance by anticipating critical situations)
- car-drivers will have a lot of information at their disposal coming from special systems which combine on-board systems and infrastructure (= "Dual Mode Route Guidance System").

Looking at these changes of traffic in general and especially of driving conditions one can see that man will have to interact much more with technical systems but also with other human beings. He will be expected to behave much more according to instructions than nowadays.
And here we are again - thinking how to solve the problems mentioned earlier. In road traffic man has learned that instructions do not have to be followed so thoroughly. Behaviour is adapted rather to one's own perception of safety and to informal behavioural norms than to official instructions.

Introduction of the previously mentioned new RTI-systems can activate the following (social-)psychological mechanisms which disturb compliance with instructions:

- Interference with the existing interpersonal communication
- Delegation of responsibility
- Behaviour adaption and speed transfer
- Imitation (by non-equipped road users)
- Problems with understanding and reliability of signals

One possibility to check if road users, especially motor vehicle drivers, are behaving according to these mechanisms is to observe and register their behaviour by following them in their own cars, using a special method of observation.

Before this observation method will be described we have to introduce and explain some expressions. Thus the philosophy of safe traffic as we understand it will become clearer.

We will talk about:

- Errors in behaviour
- Interaction
- Communication
- Interpersonal conflicts
- Traffic climate

and how to register these variables.

**Erroneous behaviour and interaction**

Errors in behaviour and interaction can hypothetically be seen as "predecessors" of traffic conflicts in the same way as traffic conflicts are predecessors of accidents. Hypothetically, comparable erroneous interactions, can end

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1) A traffic conflict is an observable situation in road traffic where an accident would result if one or more of the involved road users did not set an evasive action by braking, swerving, and/or accelerating, thus avoiding a collision. The later evasive action takes place, the more serious is the traffic conflict.
up with an accident, lead to a traffic conflict, or pass without any problems in another case, depending on circumstances, e.g., on the presence of other road users. Without defining "correct behaviour", an expert team in Vienna (see RISSER 1985) developed a scenario for deciding that a certain type of behaviour or interaction is not correct (i.e., erroneous). This team came to the conclusion that one or more of the following three criteria must be fulfilled in order to label any behaviour or interaction as "erroneous":

- Any drastic infringement of the law (e.g., driving against a red light).
- Any action causing drastic danger for oneself or other road users (even if the behaviour is legally not an infringement of the law, e.g., insisting on one's own right of way in some cases can be an example of such behaviour).
- Any behaviour that cannot be interpreted correctly by other road users, or any behaviour based on erroneous interpretation of the behaviour of other road users, in a way that danger could result out of this fact.

**Interpersonal Communication**

In connection with the discussion of erroneous behaviour the "social" context has to be considered: one is hardly ever alone on the road, behaving independently of other road users.

HYDEN (1987) stresses the aspect of interpersonal interaction or communication in road traffic, focussing on road user behaviour as social behaviour. Road users are looked upon as members of a society behaving in a complex social context, and not so much as single individuals acting according to general psychological rules.

"Communication" does not mean plain information (or omitting of information) and reaction to it. It also means deliberate neglecting of rules, thus offending others' rights and/or feelings which might lead to dangerous situations; and it also means renouncing one's own right with the aim to be cooperative and/or polite (RISSER 1988).

Communicating in traffic implies a lot of advantages:

- It is necessary to recognize the implications for one's own behaviour in the behaviour of other road users; it is necessary to make oneself understood to the other road users.
By giving signals, the fluency of traffic can be improved.

But there can arise problems as well:

- Many of those signals are not explicitly defined by laws. Such non-official signals might be misunderstood. But also some of the official signals are ambiguous. So conflicts or errors can be caused by misunderstood communication.

Interpersonal Conflicts

Sometimes when looking at traffic conflicts more thoroughly it becomes clear that the registered event has to be described in different terms: road users were actually competing or fighting for the right of way or showing their strength, etc.; to react at the last moment does in many cases not mean that the involved persons have been taken by surprise and have to react in an emergency, but that they postpone evasive action and provoke a collision course in order to intimidate each other. Such an interaction has to be defined as an "interpersonal conflict": the aspect of surprise is lacking, otherwise typical for traffic conflicts.

In the case of interpersonal conflicts the conflict's solution depends very much on the circumstances: as long as there is a possibility to discuss, conflicts can easily be solved without violence. In road traffic, however, there are two big disadvantages:

- the possibility to discuss is absent
- exchange of information with the help of one's vehicle very easily contains the elements of physical threat and violence.

In traffic most conflicts are not solved at all, leading to a social climate, which makes all kinds of friendly behaviour, solidarity, or considerate actions and reactions rather unlikely.

The "Traffic Climate"

So called "climatic" aspects represent important background conditions for the behaviour of road users: The reflected quality of interpersonal communication on the road, the perceived physical and psychological safety, including the safety of "other" persons not directly involved in traffic processes (e.g., residents), and the fluency of traffic for
all road-user groups. These perspectives often overlap quite strongly (e.g., see SACHS 1984).

The following aspects of road traffic can be interpreted as criteria for traffic climate:

- Characteristics and efficiency of interaction between road users reflect traffic climate aspects from a factual as well as from an emotional point of view.
- Together with the traffic laws and the design of roads, interaction between road users (interpersonal communication) is the basis for the smoothness of traffic processes ("smoothness" of traffic processes must not be confused with speed! Traffic can flow at a lower speed level as well, but it should "flow" for all groups of road users; for pedestrians, for cyclists, for public transport, and not only for cars.)

In the following chapters the background of the observation method "WIENER FAHRPROBE", the method itself, and some important results from different studies in the frame of which the method has been used will discussed.

**Behaviour registration methods**


Lately, in the frame of a large study done for analysing the behaviour of younger drivers by ROLLS et al. (1991) in England, the "Route assessment marking procedure" was used.

About ten years ago in Vienna a method the "Wiener Fahrprobe" was developed by RISSER et al. (1982; description see below). In the past 10 years different behaviour registration methods - but all of them based on the behaviour- and interaction variables used in the "Wiener Fahrprobe" - were used in Austria, Germany, Switzerland, and Sweden in the frame of different projects:

a) In the year 1982 driving tests were carried out on a standardized route in Vienna (RISSER et al. 1982). In this study traffic conflict situations were studied to get hints about behavioural details which raise the probability of accidents.

b) In the year 1984 drivers from foreign countries as well as Austrian citizens were observed along typical
transit-routes by following their cars. Their behaviour was analysed with respect to possible differences between the nationalities and was afterwards correlated to accidents along the route they were followed on. The observed drivers did not know, that their behaviour was registered by the two observers behind them (CHALOUPKA et al. 1985; BROHNING et al. 1989).

c) In the years 1985/1986 elderly people – both drivers and pedestrians – were observed with respect to their possible difficulties and handicaps in traffic. Drivers were accompanied in their cars, pedestrians and their surroundings were observed by using both observer descriptions and video registrations: Camera registrations were done out of a secondfloor flat near a cross road.

Behaviour was correlated to different personal performance variables at different ages, and to different accident rates (RISSER et al. 1988).

d) In 1990/91 in Vienna 150 test persons were observed by driving with them along a standardized route of 35 km (CHALOUPKA et al. 1991).

The behaviour variables (different types of correct behaviour, errors in behaviour and for the first time in interaction) were correlated to different types of accident circumstances and traffic-conflicts registered along the driving route (see below).

e) Now since spring 1992 in Vienna and Zürich a project is carried out (by FACTUM) comparing the driving style of people in a car with an electric motor with the behaviour of the same people in their own, "normal" petrol cars. It was of main interest to find out, if the small electric cars are driven in a way which is socially better acceptable than the way conventional cars are driven. With "socially acceptable" a driving style is meant which make other road-users, most of all the vulnerable ones, feel more comfortable and safe.

f) A very similar study is going on at Lund Institute for Technology, where behaviour of drivers in conventional cars equipped with a speed limiter is tested (ALMQUIST, HYDÉN & RISSER 1991)

g) The safety aspects connected to LISB, a PROMETHEUS system, have been evaluated with help of a modified
Some relations between traditional behaviour variables and variables reflecting risk

The aim of driving observations in general was and is to find out which hints for the risk for danger and in the long run for accidents there are in the behaviour of the observed persons.

The main hypothesis in connection with the "Wiener Fahrprobe" is that such hints cannot be found in the behaviour of single traffic participants but in the interaction between cardrivers (and other people). Modifications in order to put more weight on the observation of interaction and communication were implemented in 1990 (see study d above by CHALOUPKA et al. 1991). The variables derive from an older version of the "WIENER FAHRPROBE". The latest version will be discussed in the following chapter.

The "Wiener Fahrprobe"

The "Wiener Fahrprobe" is an observation method, where drivers are accompanied by two observers who have tasks of the following kind:

The "Free Observer"

This observer is called "free" because in the original version of the Wiener Fahrprobe he does not have to use any standardised observation sheet. He has to register the following variables:

- All kinds of behaviour representing a severe offence of the law and/or causing danger (e.g. increasing the probability of an accident) and/or causing misunderstandings. These types of behaviour are defined as erroneous.
- Additionally, there is a thorough instruction to register communication processes between the observed person and the traffic participants around him/her.

This means that if, during the driving test, the behaviour of the accompanied person or another traffic participant contains any aspect relevant for the behaviour of other traffic participants, this behaviour is registered and described in its relationship to the behaviour of the other traffic participants, i.e., it is described as communication.
In the latest modified version of the WIENER FAHRPROBE the interactive aspects are taken into account more thoroughly, even with respect to reliability.

The "Coding Observer"
The coding observer has to describe the behaviour of the testee along all sections of the test route using a standardized coding system that considers communicative implications in those cases, were behaviour with respect to other traffic participants (overtaking, right of way, etc.) is described. Table 1 gives an overview of the variables registered in the frame of the standardised observation.

Table 1: Coding variables for the standardised observation
- use of the lateral indicator (late, not at all)
- accuracy of lane use (extremely on right or left side of lane)
- timing of lane change in the case of obstacles (early-late)
- performance of evasive actions (abruptly, not at all)
- lateral distance to road margins or to other vehicles
- distance to preceding car
- choice of speed with relation to speed limit
- continuity of speed
- behaviour with respect to pedestrians
- driving in curves
- choice of lane at intersections with several alternatives for proceeding afterwards
- slowing down before intersections
- choice of lane on more-lane roads
- performance of lane change (hesitantly, abruptly)
- behaviour when not having the right of way, and potentially:
  - endangering road users who have the right of way
  - turning left against oncoming traffic
  - behaviour at traffic lights
  - driving past and/or overtaking other vehicles

A more thorough view on communication in traffic

The original variables of the "Wiener Fahrprobe" are described and discussed comprehensively by RISSER (1985) in AAP. Below, modifications and new variables connected to the latest version of the WIENER FAHRPROBE are discussed shortly (see CHALOUPKA 1991, CHALOUPKA et al. 1991, CHALOUPKA 1990a/b):

The standardised observation (coding observer) was completed by adding two variables:
- missing efforts to avoid (traffic) conflicts, and
- lack of anticipation concerning one's own behaviour (e.g., choice of wrong lane in spite of contradictory instruction)

In connection with the free observation, communicative aspects were stressed more than before. There exist a lot of possibilities to communicate by using car movements, car signals (indicator, etc.) or body language. Drivers partly do know "what they are saying" (i.e. they know about the communicative effects of their behaviour); but to a considerable part they obviously communicate "unconsciously" - this at least is to the impression of the observers.

In the frame of the study of CHALoupka et al. 1991 the observation of interactions was trained intensively and discussed. The registration of the main variables of communicative behaviour resulted in the following reliability coefficients after sample splitting:

+ Endangering other road users that have the right of way: .73
+ Lack of attention with respect to pedestrians and/or cyclists .60
+ Pressing others (short headways, sometimes combined with other signals) .84
+ Coordinating choice of lane to proceed after a crossroad .85

With respect to the observers' impressions and their comments of what they could observe two important aspects concerning the perception of other road users' behaviour and interaction were underlined:

a) Car drivers often do not realize that a lot of information which is coming from their motor-vehicles is a potential information source for the other road users
b) Many signals by car drivers obviously have strong emotional effects (fear, anger etc.), especially on the side of the vulnerable road users

The observers were also asked to try to register, if the actions/reactions of the observed persons were intended or happened as unreflected routine behaviour.

Independently of the fact that any communication happened on purpose or not, the registered events were labelled as "dangerous resp. negative", "neutral" or "positive" behaviour in respect to their influence on the other traffic
participants, according to everyday understanding of the meaning of communication.

Some examples for types of interactions registered in the frame of the latest version of the Wiener Fahrprobe are the following:

- Aspects of negative resp. dangerous interactions
  - does not give way (on purpose or unconsciously, e.g., because of lack of overview)
  - ignores the other traffic participants, e.g., by not adapting the speed to their presence
  - does not interrupt his/her action, in spite of necessity (e.g., overtaking in spite of oncoming traffic)
  - "presses" others (e.g., very short headway, sometimes "supporting" his/her action with flashing head light)
  - etc.

- Positive interactions
  - road users are cooperative in tackling a certain situation (by slowing down, setting a gesture, waiting etc.)
  - they show clearly what they want to do (giving signs in a redundant way, raising the chance for being understood by slowing down)
  - they take the behaviour of other road users into account
  - drivers take more precautions than the strictly necessary ones
  - a kind of communication with other road users that excludes misunderstandings
  - etc.

- Neutral interactions
  - "normal" (= standard) interactions according to the law, like waiting at a stop sign when there is traffic on the main road

Relations between Code Variables and Accident Numbers
Table 2 gives an overview of some statistically significant relations between erroneous-behaviour variables according to the up-dated observation sheet of the coding observer, and accident circumstances registered by the police during the years 1988 and spring of 1989 in Vienna.
Table 2: Relations between erroneous-behaviour variables registered by the coding observer and accident circumstances

<table>
<thead>
<tr>
<th>accident circumstances</th>
<th>observed behaviour/interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>driving in the wrong lane</td>
<td>driving extremely on the left or right side of a lane (.42)*</td>
</tr>
<tr>
<td>driving too far on the left margin of the lane</td>
<td>inadequate overtaking; (.42)</td>
</tr>
<tr>
<td>opening the car-door</td>
<td>too small lateral distances (.37)</td>
</tr>
<tr>
<td>head-on collision</td>
<td>delayed lane change in case of obstacles; (.38)</td>
</tr>
<tr>
<td></td>
<td>driving extremely on the left or right side (.39)</td>
</tr>
<tr>
<td>rear-end accidents</td>
<td>problems with lane choice (= choosing correct lane at the last moment, choosing the wrong lane); (.48)</td>
</tr>
<tr>
<td></td>
<td>exceeding speed limits (.46)</td>
</tr>
</tbody>
</table>

* = correlations between frequencies over route sections

The Relation between Communication and Traffic Climate

The registered behaviour sometimes is not erroneous behaviour in the traditional sense. However, because of its communicative character depending on the situation it can be interpreted in various ways by the other traffic participants, which leads to both different pragmatic and emotional reactions. These interpretations reflect the traffic climate.

Obviously there are places and situations where initiatives are taken that are more on the negative side seen from a communication point of view. In the report of CHALOUPKA et al. it is pointed out that "unfriendly" initiatives are mainly taken by car drivers, using the language summarised above. Reactions by other road users, mainly pedestrians, are often positive in the sense that they show "friendly submissiveness". Pedestrians give way, they renounce their right of way, they "make place" by virtually running on the last meters of the pedestrian crossings, etc.
RESUMEE

We wanted to show that efficient and cooperative interpersonal communication in traffic is a very important precondition for a safe system. Researchers dealing with the development of new high tech equipment should consider this. They should make sure that interpersonal communication will not diminish.

Moreover car and supplier industry should be aware of the fact that safety in traffic is part of the life quality of all road users, not only of the one of the drivers of motorvehicles.

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ASSESSMENT OF TRAFFIC SAFETY MARGIN IN ADVERSE WEATHER CONDITIONS.

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Abstract.

The ROSES (ROad Safety Enhancement System) project is part of the European DRIVE II initiative, and is aiming at developing and implementation of a fully integrated monitoring system for traffic, weather and road condition, to support drivers, traffic management and winter maintenance decisions under adverse weather conditions, such as poor visibility, low friction and strong cross-wind. This is achieved by integration of road-side systems and vehicle based monitoring and information systems. The ROSES system will be implemented at two different test sites and in a test vehicle.

One of the problems to overcome is the lack of a common and practical understanding of hazardous conditions. Therefore the influence of bad weather on traffic safety is studied from field observations and through model simulation of microscopic traffic behaviour.

Quantification of safety for practical use is attained by combining safety margin assessment from in-vehicle point of view and road-side point of view. In-vehicle safety assessment depends on individual parameters such as vehicle dynamics data, driver status, observation of external world through vehicle sensors and data from other vehicles or infrastructure through some communication channel. Safety margin assessment from a traffic control point of view depends on the parameters available along the road in local, regional or national traffic control centres. This includes average traffic flow data, meteo data, incidents, etc.

Within ROSES, an integrated safety assessment procedure will be proposed and pilot tests will be carried out to evaluate and improve this procedure and to demonstrate its behavioural and safety effects.

1. Introduction, the DRIVE-ROSES project.

Bad weather is a major cause for interurban accidents. Roughly one third of all accidents occur under conditions of adverse weather, the largest part of which take place on a wet road, see fig. 1.

Bad weather is experienced as a combination of additional forces and moments on the car such as for cross-wind, a sometimes very sudden reduced visibility during fog, heavy rain or snow, and a reduced friction for situations such as black-ice, rain and snow.
BAD WEATHER CAUSE FOR ACCIDENTS

CLEAR 65%
BAD WEATHER 35%
INTERURBAN ACCIDENTS

Figure 1.: Accidents under bad weather.

Avoiding these accidents is not achieved in a simple straightforward way for the following reasons.
First, drivers are not able to estimate the effect of bad weather on driving performance.
Under low friction conditions (aquaplaning, ice) they tend to overestimate the friction and thus underestimate the stopping distance. In addition, French traffic data under fog conditions during day and night show that, in spite of the fact that drivers tend to reduce their speed below a visibility distance in the order of 100 m, they are still driving too fast to brake safely under emergency conditions [2], that is within their visibility range.
Second, dangerous weather conditions and their impact on road conditions are difficult to predict with sufficient reliability. Third, there is a large variation in vehicle and driver performance under adverse weather conditions. All of these reasons contribute to the poor credibility of the present warnings, offered to the drivers.

The DRIVE I CROW project (Conditions of ROad and Weather, 1989 - 1991) was dealing with this subject. The project has been directed to road-side monitoring and road-side hazard warning, yielding a concept for a road processor, the CROW Control Centre, new sensors, an accident safety algorithm and forecasting methods and strategies.
As an extension of the CROW project, the DRIVE II ROSES project was launched in 1992, with the goal to reduce the number of interurban accidents caused by bad weather, using a
better information exchange to the driver and the road manager about unsafe road conditions, which is required to be reliable, accurate and easy to perceive.

The key objective of ROSES is to extend the CROW Control Centre to a fully integrated monitoring system for traffic, weather and road condition. This ROSES system will include both in-vehicle and road-side monitoring, control and warning systems. It will be tested at two different locations in Europe, in The Netherlands with special emphasis on maintenance support, traffic control and information, integration in the existing road data network further developed within the DRIVE II GERDIEN project, and vehicle-road side information transfer, and in Wales with special emphasis on cross-wind impact on sensitive vehicle categories within a traffic control and information framework.

2. In-vehicle safety margin.
Stand-alone in-vehicle safety margin depends on input parameters, measured at the actual moving location of the vehicle. These parameters include external parameters such as road friction, road geometry, road type, visibility, side winds, and internal parameters such as the actual driving state and the driver status.

A notion of safety is derived from the comparison of the external conditions and the relative performance of the vehicle driver system with respect to their actual conditions, which in turn depends on the external conditions and the dissemination of external information to driver and vehicle. On the other hand, the absolute performance may have an effect on the actual driving conditions, a mechanism which is usually referred to as risk compensation.

Friction between tyre and road is the fundamental mechanism in risk evaluation and safety assessment. It has to be taken into account in any safety enhancement system where some kind of lateral or longitudinal change in motion is expected. Examples are Collision Avoidance Systems (CAS) and Intelligent Active Cruise Control (IACC).

Consequently, since all of these systems require some safety margin assessment model, descriptive models of tyre behaviour under various conditions are essential and will be derived in ROSES.

Starting point for ROSES will be an in-vehicle safety margin assessment system, developed by Porsche, being able to identify the actual road friction just ahead of the car, and its possible effect on vehicle behaviour, in terms of potential acceleration in both longitudinal and lateral direction.

From these potential accelerations, different thresholds can be suggested related to different warning levels, and depending on driving style, road type, etc. This means that, for example during cornering, a momentary maximum desired lateral acceleration, depending on friction, slope, is compared to the actual lateral acceleration depending on curve radius and speed. The driver is able to understand his own safety level and may correct appropriately by slowing down and, on the long run, learn how to tune to an optimal safe speed in similar circumstances.

A recommended speed may be defined, depending on the driver status, the desired stopping
distance and a comparison of potential acceleration and actual driving state.

The autonomous system is restricted to a very local determination of friction and, in order to avoid abrupt changes in road condition, needs to be extended with preview information on the friction condition ahead of the vehicle.

This can be achieved by using information on forthcoming variation in potential acceleration and visibility range, communicated from infrastructure and obtained either from roadside sensors or from data transmitted from similarly equipped vehicles ahead.

3. Road-side safety margin.

A road-side based safety margin assessment model, such as used in the CROW Control Centre [4] is based on road and meteo sensor data, implemented at different spots along the road. These data can be processed to averaged data (over time-intervals of specific length) yielding mean velocity, mean following distance and standard deviations to account for variation in traffic behaviour within clusters of vehicles.

In CROW, the following four different types of risk were distinguished:

- Cornering under low friction and/or cross-wind
- Excessive lateral deviation due to cross-wind and/or low friction
- Poor visibility and/or low friction
- Low friction for high traffic density.

Both present and forecasted risk are determined expressed as the difference between a “safe speed” (accidents are just avoided) and the actual speed behaviour.

This safety assessment model is incomplete and will be extended within ROSES.

* Lane change behaviour, occurring during overtaking and at motorway entry/exit are not (yet) considered.

An “Ansatz” to the safety margin assessment under these circumstances might be the fact that the traffic risk depends on speed difference and following distance, similar to head-tail situations. This suggests the derivation of a “Risk curve” in the plane of potential speed difference versus potential following distance, depending on road geometry, average traffic conditions, time of the day, etc., and describing the boundary of the region considered to relate to safe driving.

Examples:

1. Head - tail

   Speed difference refers to difference in speed between heading car and following vehicle. A small distance is allowed for a small speed difference and a large distance allows for a large speed difference.
2. Lane change on motorway
   Speed difference refers to the difference in speed between the two lanes, corrected for variations within the lanes. Distance means the distance between vehicles in the second lane.

3. Overtaking on a rural road.
   Speed difference refers to the difference of the absolute values of the velocities at each lane (i.e. a relative difference), corrected for variations within those lanes. Distance refers to the distance between the vehicles in each lane.

4. "Entering ramp"
   Speed difference refers to the difference in speed between the entry road and the main road. Distance refers to the distance between vehicles on the main road. This case is familiar to example 2.

* The effect of bad weather on traffic flow, efficiency and its feedback to traffic safety is not clear.
* Poor visibility may be a combination of reflecting headlights, the falling rain or snow, and splash and spray by trucks and passenger cars. Useful quantitative information about this type of visibility is hardly available, see [7].
* Observation is restricted to road condition, whereas road friction is the necessary input to the safety margin algorithm. The variety in possible road circumstances doesn't allow an accurate friction evaluation in all circumstances.
* The occurrence of (articulated) commercial vehicles has an effect on traffic safety. This aspect needs further attention.

Finally, the information required for a road station is restricted to discrete, preselected points. Similar data, continuously obtained along the road by passing vehicles allow for an update of the road friction or visibility distance at these points plus a reliable interpolation between these local spots. This will contribute to higher reliability of the road data and hence, a higher credibility of the necessary warning to the road user.

   A large variation in vehicle performance will result in a large variation in safe speed based on the in-vehicle safety margin approach. Hence, large deviations in both velocities and following distances will occur in the extreme situation that every road user will drive at its individual recommended speed. It is clear that it should be doubted whether such a single approach will contribute to traffic safety.
   Hence, safer vehicles will not automatically lead to safer traffic.
   On the other hand, road-side based warnings, based on inaccurate data and not taking into account the variation of vehicle performance (by leaving some responsibility with the driver) will have an insufficient credibility to a large group of drivers and will therefore be ignored.
   The main goal of ROSES, a monitoring system for traffic, road and weather conditions to support drivers and road management, can only be reached by integration of the two
approaches described in the preceding sections. This is confirmed in [3]. We quote:

**Traffic safety** is the safety outcome of the operation of the whole traffic system: i.e. vehicle plus ATT (Advanced Transport Telematics) plus road users plus environment.

The relationship between vehicle and central safety exists at different levels as expressed in figure 2.

![Figure 2: Vehicle- and central safety margin.](image)

**Ad 1.** The global risk may be estimated from the "cumulation" of individual risks, and from average traffic data. It means that for each of the individual road users a risk value is calculated. From these individual values one can determine averages and standard deviations, which are needed to evaluate the total safety situation (safety indicators). Such an individual risk value could be based on a comparison of deceleration distance and inter-vehicle distance (cf. CROW), TTC (time required for two vehicles to collide if they were to continue at their momentary speed), rearward amplification of speed variations for certain frequencies for realistic initial distances and speeds, etc.
This approach is useful in simulation studies beforehand, and for interpretation of traffic behaviour in the pilot, from measured individual data (speed, distances) from conflicts ("almost"-accidents), or from measured average traffic data (mean speed, deviation in speed). In that sense one is able to:

- calculate average risk from individual behaviour
- determine average risk from average traffic data

and from the correlation between the different results derive improved central safety margin assessment algorithms.

Ad II.:
This link refers to Section 2 on in-vehicle safety margin. It helps the driver to better understand the impact of changing weather and road conditions on traffic safety. The driver is still responsible and takes the necessary actions. Only in very special emergency cases, when the driver is too late to respond, additional control of the car itself may be useful.

Ad III.:
This link refers to Section 3 on central (or traffic management) safety margin. It allows for average safety assessment, accounting for expected weather condition and therefore road condition and local meteo condition. The data may be used by the road maintenance service to avoid poor road conditions.

Ad IV.:
This link relates to the distinction between micro- and macrotraffic behaviour. It involves bidirectional communication to improve the input data for both the vehicle- and road side safety margin processing. Hence, there must be a "little bit of IV" in both II and III.

In case of II, preview data must be transmitted on the variation of friction ahead of the vehicle from which a "safe" speed can be derived.

In case of III, information transmitted by equipped vehicles (which could be "maintenance vehicles" for the time being) will contribute to a higher level of accuracy of the input data and hence of the risk assessment.

5. Conclusions and further activities.
Roughly one third of traffic accident occur under bad weather conditions. A road- and weather condition monitoring system, to assist driver and road management to cope with these hazards, can only be successful if:
- the input data (traffic, road, meteo) is accurate, sufficient (with demands to the monitoring network) and reliable,
- driver information (warnings, recommendations) has a high level of credibility,
- both individual vehicle/driver behaviour and the micro- to macroscopic traffic behaviour as a result of weather hazards must be addressed in the assessment of traffic safety, defined as the safety outcome of the operation of the whole traffic system.

These conditions are fulfilled, neither by the individual in-vehicle safety margin model nor by the traffic (central) safety margin assessment approach. Each of them account for some of these requirements. An integrated safety margin model has the potential capabilities to deal with these deficiencies, successfully.

The derivation of an integrated safety margin assessment is one of the topics in the DRIVE ROSES projects. This requires bidirectional communication between road-side beacons and vehicles, to offer better preview information to the driver and with that a better perception of hazardous conditions and, in addition, allow for a high level of accuracy and therefore a higher level of credibility of road-side warnings.

The interaction of in-vehicle and road-side traffic assessment will be further elaborated within the ROSES project. The following activities will be carried out, where distinction is made between pre-trial stage (simulations, controlled environment tests) and the trial stage (i.e. the "on the road" evaluation, or pilot test).

a. Pre-trial stage.
- Identification of safety indicators.
- Parameter sensitivity studies.
  Studies based on micro-traffic models, including safety margin postprocessing in terms of potential safety curves (potential acceleration, speed difference versus following distance) and safety indicators.
- PRO-GEN traffic safety checklist, to serve as a preparation for the ROSES pilot, as well as a basis for interviews.
- Pre-trial interviews of drivers, operators, guests, traffic management.
- Presentations and liaison within the DRIVE community.
- Pre-monitoring and data collection at the pilot site, used as validation of the micro-traffic studies.
- Simulator studies and model calibration.

b. Trial stage.
The trial stage includes conflict studies (see [3] and ad i above) and post-trial interviews.
6. References.


APPROACHES TO POOR-VISIBILITY ROAD ACCIDENTS: MOTIVATION AND PERCEPTION

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Abstract
Motivational theories of driver behaviour invoking risk homeostasis or behaviour adaptation have elicited considerable interest. However, their generality may be less than sometimes assumed: specifically, they appear incomplete with respect to poor-visibility road casualties. Motivational theories imply a broadly constant rate of accidents, given steady motivational parameters, but accidents are consistently more frequent in poor visibility. An implicit assumption of motivational theories is that input to the driver is accurately and veridically processed in order that risk can be adequately computed. However, the driver's motion perception is likely to be much dependent on relative motion at the retina: in poor visibility the associated processing may be degraded - as reflected in poor thresholds for detecting object motion - or non-veridical - as reflected in simultaneous motion contrast. This paper illustrates the difficulty of developing global theories to explain "real-world" activities such as driving: theories addressing restricted aspects of road behaviour may be more fruitful.

Introduction
Persistently high rates of road casualties - in Great Britain they were 300,000+ per annum during the 1980s (Department of Transport, 1990) - cast doubt on the long-term effectiveness of ameliorative interventions. For example, the initial effectiveness of compulsory seat-belt usage (Conybeare, 1980) and novel road markings (Shinar, Rockwell, & Malecki, 1980) has been often followed by a drift back to the previous status quo. This suggests that the road-user's performance may be best understood by reference to motivation, specifically a tendency towards a relatively fixed "target" level of risk. This target risk is reflected in speed, following-distance and so on. Measures that in the short term reduce casualties will over time be counteracted by, for example, faster driving.

This paper is directed at casualty rates in poor visibility: these are persistently higher than in good visibility. Thus, an unduly high proportion of accidents on UK motorways are multi-vehicle shunt collisions caused by excessive speed and close-following in fog (Parker & Cross, 1981; White & Jeffery, 1980). Another example lies in pedestrian casualties at night. Smeed (1977) investigated UK pedestrian casualties (a) during late-afternoons around switches to and from daylight saving and (b) at
clock times which vary from lightness to darkness through the year. Casualty increases associated with night were from (a) 63% and from (b) 170%. Regarding (a), given maximum control of other conditions, data can only be collected over a few days around clock changes: since there will be a lack of complete switching between light and dark at the time of investigation, (a) would underestimate the effect of darkness. Additional effects such as alcohol consumption and fatigue contribute to (b). Therefore, the true increase in pedestrian casualties due to darkness is probably intermediate between the two figures.

It is intended to outline two established motivational models - risk homeostasis and behaviour adaptation - regarding their implications for poor-visibility casualties. Developing a theme introduced by Reinhardt-Rutland (1992), it will be suggested that motivational theories are not complete in this regard. Instead, the problem might more usefully invoke factors of perception; these will be outlined briefly. Suggestions will be made about inherent limitations of motivational models.

**Risk Homeostasis**

Most motivational models make explicit reference to risk; probably the best known of such models is risk homeostasis (Wilde, 1982). In brief, this postulates a hypothetical risk-homeostasis mechanism entailing cultural, social, psychological and economic inputs. To incorporate high-casualty groups such as young single males, long-term adjustment of the individual's target risk-level must be possible; also, short-term effects may arise from drugs and averted attention. Target risk-level can be reduced by stringent economic factors and by incentives to avoid accident instigation (Wilde, 1991). Risk should otherwise be reasonably constant.

While risk homeostasis has undoubted intuitive plausibility, detailed implementation is problematic (Adams, 1988). For example, (a) the abstractness of many factors - especially cultural and social factors - militates against straightforward investigation of their contributions to risk; (b) the empirical evidence is often inconclusive, a point exacerbated by the uncertain time-scale over which readjustment operates following intervention (McKenna, 1988).

Risk homeostasis also seems incomplete regarding poor-visibility road accidents. It might be argued that poor visibility falls outside the scope of risk-homeostasis theory in that it is too infrequent to have a consistent effect on the risk-homeostasis mechanism: poor visibility is deleterious because road users do not generally expect it. However, this is implausible for many road-users. Of necessity, many journeys are undertaken in darkness during winter. Also, road-users living in areas of high precipitation - such as the seaboard of Europe - are likely to be familiar with the resulting poor visibility due to that source. The persistent increase of casualties in poor visibility might be related to a short-term shift in target risk, comparable to that
suggested for drug ingestion. However, the various factors postulated to shift target risk-level are largely motivational in their effects. It is difficult to see how poor visibility could fall into this category. Therefore, target risk-level should remain much the same during both good and poor visibility. In fact, poor-visibility accident rates may directly contradict risk-homeostasis theory. If an ameliorative effect - such as compulsory seat-belt usage - is counteracted by, say, increased speed, so that accident rates increase to their pre-intervention rates, the opposite should be true for a persistently deleterious effect: familiarity with the deleterious effect should be followed by sufficient adjustment of speed and so on to reduce accident rates to levels applying when the deleterious effect is absent.

Behavour Adaptation

Versions of the theory
A theory of behaviour adaptation to explain habitual driving performance draws on research into classical and operant conditioning in non-humans. Different contingencies of aversive and appetitive stimuli determine roadway behavior: although aversive stimuli generally have a persisting influence on behaviour, on the road - in the form of accidents or near-misses - they are rare in relation to the great distances travelled. Appetitive stimuli - including speed, early arrival at destination and "macho" factors prevalent among some of the driving community - therefore can have an inordinate effect on driving behaviour (Fuller, 1984).

Although the concept of target risk-level is not explicit in behaviour-adaptation theory, presumably any individual has a desired balance-point between appetitive and aversive stimuli, otherwise appetitive stimuli might have an even greater effect than they generally do - accepting Fuller's point about the paucity of aversive stimuli for many individual drivers. That the effect of appetitive stimuli is constrained is reflected in the performance of even relatively ordinary automobiles, which is such that many have the capability to exceed nearly twice the UK speed limit: presumably for many of their drivers the appetitive stimulus of speed is sufficiently constrained to prevent exploitation of their vehicle's full potential.

A prominent feature of behaviour-adaptation theory is delayed avoidance responding, referring to the tendency to ignore stimuli preceding potential aversive stimuli - such as the first sighting of a "blind" curve on a narrow road carrying light traffic. Responding is delayed until it is clear that there is an actual aversive stimulus requiring immediate avoidance - for example, as the curve is negotiated a large oncoming vehicle emerges. The above can be expressed in another way: the curve is an inadequate conditioned aversive stimulus.

While delayed avoidance responding could be a consequence of the paucity of aversive stimuli, a later version of the theory
(Fuller, 1988) adduces evidence from non-human laboratory studies that delayed avoidance responding will be preferred inherently to anticipatory avoidance responding, almost irrespective of reinforcement contingencies (Hineline, 1981).

**Behaviour adaptation and poor visibility**

Of course, there are effective conditioned aversive stimuli: traffic lights and other signs conveying orders at traffic or pedestrian intersections are obvious examples. What distinguishes these from ineffective conditioned stimuli is the frequency of associated aversive stimuli and, possibly, their temporal proximity to aversive stimuli. Poor visibility should be a candidate conditioned stimulus for more cautious behaviour, but may fail because the accident rate associated with poor visibility — although greatly elevated — is not sufficient to have a substantial effect on behaviour. However, the borderline between effective and ineffective conditioned stimuli is far from clear. The issue is further complicated by the implicit assumption of a target balance of aversive and appetitive stimuli, which suggests that there may not be a clear-cut distinction between a stimulus that is never effective as a conditioned stimulus and one that is always effective — rather there is a continuum of effectiveness. The validity of an explanation of poor visibility as an ineffective conditioned stimulus must await clarification of these issues.

On the other hand, if it is argued that delayed avoidance responding is inherently preferred to anticipatory avoidance responding, irrespective of contingencies of aversive and appetitive stimuli, then any explanation for poor-visibility accident rates invoking behaviour adaptation is dubious. If features of the road such as blind curves fail to be successful conditioned stimuli, they are nonetheless plausibly associated with increased aversive stimuli. In contrast, poor visibility does not intrinsically entail increased aversive stimuli: fixed hazards and traffic flows should be much the same at a given time and location, whether visibility is good or poor. Hence, the reason for increased accidents in poor visibility is unclear in a conditioning model, with its emphasis on environmental contingencies. It may be argued that conspicuity and acuity suffer — imminent aversive stimuli are less easily detected. However, this is tempered by the key point of delayed avoidance responding, that the driver only responds at the latest possible opportunity, even if information for the impending aversive stimulus has been available for some time. Of course, if the aversive stimulus is concealed by, say, a blind curve, it will be no more visible in good conditions than in poor conditions.

Other evidence casts doubt on the importance of conspicuity and acuity in poor-visibility accidents: while the driver must first detect a potential hazard before any action can be implemented, relatively complex aspects of perception may be more pertinent (e.g., Wetherell, 1986). Consistent with this assertion, aids to conspicuity — such as retroreflective material and high-intensity rear vehicle-lamps — have had little effect in reducing
casualties in poor visibility, even though such aids are visible to drivers well before an avoidance response is required (Shinar, 1985; Sivak, 1979). Also, young drivers - those most likely to have good acuity - are those most likely to have accidents at night (Testu, 1990). Since behaviourism assumes adequate uptake of environmental information (O’Neill, 1968), issues of perceptual processing are outside the scope of behavioural speculation.

Visual Perception in Poor Visibility

Detecting driver’s own motion is mainly visual
Much of the material in the following sections has been discussed elsewhere (Reinhardt-Rutland, in press), so it will only be outlined in brief here. The classic account of perception of one’s own motion refers to kinaesthesis, based on muscle and joint motion, and the inner-ear vestibular organ, responsive to acceleration and deceleration. For the driver, such sources of information are much reduced. The vehicle’s engine takes over from muscles and drivers often travel at a fairly steady speed so that the vestibular organ is unresponsive. To an extent vehicle noise may substitute for these senses, although this is probably of decreasing value with the increasing smoothness of modern vehicles, and may be drowned out by a radio or conversation. Thus detection of the driver’s own motion must be largely visual (Reinhardt-Rutland, 1988). Any motion we make, whether driving or not, entails opposite motion in visual sensation - the “flow-field” (Gibson, 1979). Note that the flow-field is not always adequately effective for the driver; for example, long periods travelling at steady high speed may lead to a negative adaptation effect, causing underestimation of own speed (Denton, 1980).

Relative visual motion
Perceiving motion around us requires analysis of retinal-image motion. If the eye were static, a moving object would elicit a moving image and a static object would elicit a static image. However, the eye is rarely static: image motion also results from the eye moving past a static object. To determine the origin of an image motion, the visual system could register both image motion and eye motion, and compare them. When image motion matches eye motion, object stationarity is perceived. When image motion does not match eye motion, object motion is perceived (Wertheim, 1981). Note that eye motion is both relative to the head and indirect due to head or body motion. In support of this model, an afterimage - created by staring at a bright object - appears to move if one moves one’s eyes in the dark. Since an afterimage is fixed with respect to the retina, this must be because eye motion is registered (Mack & Bachant, 1969). However, as already noted, sources of information for the driver detecting own motion are attenuated: the driver’s eye motion will be inadequately registered, so one component for comparison will be incomplete. Consistent with this, drivers’
detection of a followed vehicle's headway is poorer than predicted from laboratory studies with static observers (Probst, 1986). However, this cannot be the full story, since the pattern of motions around the driver is adequately detected in general—at least if visibility is good.

The reason for this lies in relative visual motion. Its importance is illustrated thus. Detection of motion of a lone luminous object in the dark is poor, but excellent if a static luminous object is also present: the object now moves relative to another object (Shaffer & Wallach, 1966). Relative visual motion is also important for perceiving relative distance. For a moving observer, nearby static objects move visually faster than distant static objects: for example, from a moving vehicle the close trackage rapidly moves past a distant group of trees. This cue, known as motion parallax, can reliably lead to correct perception of relative distance (Rogers & Graham, 1979).

The difficulty in responding to motion in isolation bears on pedestrian accidents at night. Despite the proven increase of drivers detecting pedestrians due to retroreflective material, its use does not much affect pedestrian casualties (Shinar, 1985). One reason for this seeming paradox may be this. While retroreflective material affects the conspicuity of the wearer, the environment around the wearer is unaffected: the driver still must perceive the pedestrian's motion and distance when relative visual motion may be sparse. As support, Polus and Katz (1978) found that street lighting, which affects conspicuity of pedestrian and environment, is effective in reducing accidents. In a different context, many UK police authorities now regard lighting as a priority for motorways (Reinhardt-Rutland, 1981).

In part, this reflects the apparent ineffectiveness of high-intensity rear lamps (compulsory UK equipment since the early 1980s). Among other shortcomings, their beneficial effect is confined to conspicuity of the vehicle using them.

**Visual motion contrast**

Relative visual motion appears to be so important for perception that mechanisms in the visual system exaggerate it, often at the expense of veridically perceiving absolute motion. Thus, a moving object appears to move fast if surrounding objects move slowly and slowly if surrounding objects move fast (Loomis & Nakayama, 1973). Another example is the illusory motion of the moon against clouds on a windy night. Such examples of motion contrast are reflected in motion aftereffects — indicators of sensory processing (Reinhardt-Rutland, 1988) — and analogous activity in motion-sensitive neurons (Hammond, Mount, & Smith, 1986; Mandl, 1985). Contrast, aftereffects and analogous neural activity are general to perception, affecting brightness, orientation, colour and size, as well as motion (e.g., Coren & Girgis, 1978).

Motion contrast could affect the driver following a vehicle travelling at his/her own speed. Relative speed is zero, so the vehicle is visually static. However, motion contrast — opposite in direction to the flow-field — may cause the followed vehicle to apparently recede: the driver would overestimate its speed and so
tend to close-follow it. It may be argued that other sources of information prevent this. In particular, moving closer to the followed vehicle causes visual expansion; however, this may not be effective unless the driver is closing in fast (Van der Horst, 1991). In common with other forms of contrast (Coren & Girgus, 1978), motion contrast can be elicited in the laboratory with highly impoverished stimuli (Reinhardt-Rutland, 1985), which may explain why close-following is frequent in fog (Parker & Cross, 1981; White & Jeffery, 1980).

Informally confirming the above, drivers experience motion contrast via the "vista paradox". Suppose a driver moves towards a topological convexity which obscures the environment ahead, but beyond which can be seen, say, a distant group of houses: the houses may appear to recede. Visually, the stimulation is rather similar to that of the driver following another vehicle. The houses, because of their great distance, are virtually static in visual terms; the environment up to the topological convexity elicits the most salient part of the driver's flow-field, which in turn elicits motion contrast of the houses (Walker, Rupich, & Powell, 1989; Reinhardt-Rutland, 1990).

Implications
Any theory should entail reasonably well-defined implications relating to the issue to which it is directed. Two practical implications emerge regarding relative visual motion. First, roadway lighting should be particularly effective at reducing accidents: it increases the salience of relative visual motion in poor visibility. Second, information conveyed to road users by way of propaganda campaigns and the like should be careful not to claim too much for aids to increasing conspicuity such as retroreflective material and high-intensity rear fog-lamps. Such aids may alert the driver to hazard, but they have little effect on motion and distance perception, so incompletely assist in instigating appropriate action.

Other implications are not encouraging: since perception is such a phenomenally immediate and vivid aspect of psychological processing - "seeing is believing" - road users may not be readily convinced of the potential for misperception. Indeed, it has long been known that drivers accept their perception of own speed, even if contradicted by speedometer readings (Denton, 1969). A change in the behavior of road users in poor visibility may have to resort to supplementary roadway information. Ever-improving technology to identify dubious driving behaviors such as close-following may make this more feasible (Hellier-Symons & Ray, 1986; Rothengatter, 1991).

Discussion
This paper has proposed that increase in accident rates in poor visibility be considered in terms of how visual motion is analysed, in preference to motivational factors. The theory addresses a dubious implication of motivational theories that
accident rates are necessarily correlated with motivational factors in all conditions. Consideration of the adequacy of perception raises another issue: the notion of a target level of risk is only meaningful if it can be demonstrated that all information determining the target level is veridical. There may exist some highly-subjective target risk-level, but its effect on the real world would presumably fluctuate unpredictably if information is sometimes veridical and sometimes not.

Another point can be directed to delayed avoidance responding in behavioural adaptation theory. The tendency to delay avoidance responding might be explained alternatively in terms of perceived time-to-collision. Following the demonstration in many species of startle responses to simplified "looming" stimuli (Schiff, 1965), it is possible that time-to-collision might be computed directly from looming stimuli (Lee, 1976). In the context of the roadway, the experience and speed of the driver are also important (Cavallaro & Laurent, 1988; Van der Horst, 1991); perceptual factors associated with poor visibility must also modify perceived time-to-collision. The overriding factor in determining avoidance responses may lie in minimum time-to-collision; any times-to-collision greater than this minimum may have little salience for the driver, since they do not require immediate responses.

The evidence points to a problem in applied research - that of identifying global theories that can cope with the full complexity of the "real-world" activity to which they are applied. For example, a theory may originate in a particular area of psychology - this applies to behavioural adaptation - so may overlook implications available from other areas. Alternatively, a global theory may become so complex that its predictive power becomes severely limited (Marx & Cronan-Hillix, 1987). This may apply to risk homeostasis with its multiple inputs. Arguably, a concept of target risk-level, as measured primarily by reference to objective accident statistics, has no more explanatory power than as an averaging effect accumulated from many factors, analogous to statistical regression towards the mean. The often inconclusive evidence for risk theories and related issues, such as the time scale over which risk-level might stabilise after the introduction of a putative safety-measure (McKenna, 1988), support this assertion.

Given that their scope is sufficiently defined to reasonably exclude factors which they do not address, theories explaining restricted aspects of a complex activity, such as the perceptual theory outlined here, may be more useful in that they entail relatively clear implications. In this context, it would be helpful to isolate putative factors contributing to motivation. However, as already indicated, many candidate factors are abstract: how and to what extent might one validly measure "macho-ness"? Like many other human attributes, risk is a slippery concept. Furthermore, the relationship between psychological and statistical risk is unclear (Adams, 1988). Many human activities - even pouring hot water from a kettle - have the capacity to injure, but we would hardly label them risky.
Another example: the ‘troubles’ of Northern Ireland seem to entail more risk to the Northern Irish population than do the roads, yet mortality rates for the roads are nearly twice as high as for the ‘troubles’ (Hermon, 1989). Until such issues can be adequately resolved, the explanatory scope of motivational theories must be viewed with caution: current motivational theories arguably do little more than remind us that measures designed to reduced casualties can have complex and often unfortunate side-effects.

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COMPARATIVE TESTS TO ASSESS THE EFFECTIVENESS OF HIGH-RELIEF PAINTS

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Motorway companies have been experimenting various methods of road marking using high-relief paints for several years now. It is known that these paints increase safety since they are far more easily visible in wet weather and the audible effect generated in the vehicle when it runs over them counteracts fatigue or somnolence.

As part of a general survey, ASSECAR (1) wished to determine users' reactions to the various types of marking used and, particularly:
- their reactions to the audible and vibration effect produced when the vehicle runs over the strip;
- the improvement in visibility of the strips by day compared to conventional paint as well as the visual effectiveness;
- the improvement in safety offered by audible strips.

CERC MARKETING Company was selected to carry out a "marketing"-type enquiry: the objective was to have comparative experimental tests carried out on different types of marks by normal road-users, i.e. drivers of either private cars (PC) or heavy goods vehicles (HGV).

The main characteristics of the test were:
- typical zones, selected as being representative of protuberance markings used;
- the test was purely comparative, it did not aim to assess absolute performance but only differences between the various typical zones selected;
- it involved both normal drivers of private cars and professional drivers of semi-articulated vehicles;
- it was carried out under real-life conditions with the drivers noting their reactions immediately.

Consequently, 36 typical zones, containing different types of paint, i.e. either with bars or with "pimples" of differing heights and spacing, were selected.

(1) The Association des Sociétés Françaises d'Autoroutes Safety Department.
This note explains how the enquiry was carried out amongst 248 PC and HGV drivers, gives the results obtained and draws the main conclusions concerning the systems which offer the greatest efficiency in the case of heavy goods vehicles and private cars.

I - PREPARATION OF THE ENQUIRY

The 14 types of audible strip tested

a) Selection of audible strips

At the request of ASSECAR, CERC MARKETING selected 36 potential tests zones, representing a total of 347 km, from the roughly 100 zones (representing more than 500 km) that exist on the 5,700 km toll motorway network. Those 36 physical zones were then grouped into 14 classes (known as "typical zones") representative of the range of tests, companies, regions and districts.

b) Eight types of bar and six types of pimple

The survey therefore covered 14 typical zones comprising 8 "bar" and 6 "pimple" zones:

8 bar zones:
A plastiroc "short" 600-650 9 to 11 mm
B plastiroc "long" 1000 4 to 11 mm
C sonorive FLC "central" 1000 8 to 10 mm
D sonorive FLC "end" 1000 7 to 12 mm
E somaflex "short" 530-740 4 to 6 mm
F somaflex "long" 1050 5 to 6 mm
G ecoflex "2m" 1900-2000 12 to 14 mm
H sonorive FLC "2m" (*) 1900-2000 10 to 12 mm

6 pimple zones:
M "large" 5-6-5-6 80-100 4 5 18
N "small" 5-5-5-5 90-130 4 40 18
O "half-strip" 120-130 4 40 18
P "close-pitch" 65-100 3,5 20 18
Q "+ 20 mm pads" 90 5 40 18
R "+ 14 mm pads" 90 5 40 18

(*) FLC : bar on a 30 cm pad.
The main test conditions
a) The test procedure: realistic conditions
Each driver recruited was individually briefed. He was offered 2, 3 or 4 zones along his route and asked to observe and assess them as he passed through them. After each zone, he was to stop in the next parking area and note his evaluation and comments in a report form. He did this for each zone and then added his final observations, on each test zone, to form a final global assessment in the form of a mark between 1 and 10.
The questionnaire used is given in appendix 1.

b) Test periods
The drivers did the tests in two periods:
- mainly, from the 20th April to 30th May 1991
- an additional period from the 23rd to 30th October 1991.

c) Number of comparative tests
A total of 790 tests were done on the 14 typical zones, including 378 by 120 private cars (PC) and 412 by 128 heavy goods vehicles (HGV).
To ensure that the results were meaningful, each typical zone was tested:
- an average of 56 times, with a minimum of 25 and a maximum of 108;
- by comparison with an average of 2.5 other typical zones with a minimum of 1 and a maximum of 5.
In addition, it should be noted that all drivers had previous experience with audible strips to form a basis for comparison.
The chart in appendix 2 indicates the comparisons which could be made, in practice, due to geographical restrictions.

II - CLEAR OVERALL RESULTS
The overall results are summarized below, without entering into details on the report sheets collected.
The average marks allocated to each type of strip accurately represent the situation: both PC and HGV (with a few restrictions) approve existing bar types while existing pimple types are appreciated by PC but rejected as ineffective by HGV drivers.

<table>
<thead>
<tr>
<th>Average mark per 10 drivers</th>
<th>PC</th>
<th>HGV</th>
<th>All vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 BARS tested 424 times</td>
<td>6.5</td>
<td>7.1</td>
<td>6.8</td>
</tr>
<tr>
<td>6 PIMPLES tested 366 times</td>
<td>7.0</td>
<td>4.7</td>
<td>5.85</td>
</tr>
<tr>
<td>All types</td>
<td>6.7</td>
<td>6.0</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Except in the HGV/Pimples case, the marks are good.
III - CONCLUSIONS AND RECOMMENDATIONS FOLLOWING THE ENQUIRY

III-1 Pimples
Pimple-type audible strips are excellent for private cars but inefficient for heavy goods vehicles.
Their main effect on PC is a "noise in the head" which basically depends on the pitch between the rows of pimples and the vehicle speed.
It would seem that, for PC travelling in the right-hand lane at 120 km/h, the pitch should be greater than 80 mm and less than 120 mm. Below 80 mm, the noise becomes a "whistle" which some drivers find highly disagreeable. Above 120 mm, it becomes too weak.
Vibrational effects are small but do not seem to be necessary, or even desirable, for PC.
The height of the pimples must be carefully checked at application and be between 4 and 5 mm.

III-2 Bars
Audible strips with bars are more efficient for HGV but must remain acceptable to PC.
Their main effects are:
- an audible effect. If this effect is reasonable for HGV, it is generally found to be too strong by PC and to be felt rather than heard. This non-compatibility must be resolved by carefully selecting a combination of pitch and height;
- a vibrational effect (similar to that above for PC) which, apparently, could be made acceptable by selecting a relatively short pitch (less than a meter) and a mean height between 5 and 9 mm or by a finer FLC-type solution.

IV - ACTIONS FOLLOWING THE ENQUIRY

Obviously, the comparative study described above is part of a wider research and development programme. Appendix 3 gives a list of the main documents raised by this programme but the details are outside the scope of this note.
Following this programme, Motorway Companies have decided to generalize the use of high-relief marking and intend to install 4300 km of such paint along the right-hand edge of motorways (i.e. along 2150 km of motorway) within 3 years.
Priority will be given to the following areas:
- zones in which many accidents occur due to vehicles running off the road to the right due to a lack of vigilance;
- zones where many accidents occur due to fatigue and somnolence;
- zones where the hard shoulder is narrow or non-existent;
- zones where there are no safety rails at the edge of the hard shoulder including, in particular, left-hand bands (in right-hand bands, drivers are guided by the rails along the central reservation but there is no such possibility in left-hand bands) and along embankments between 2 and 4 m high;
- zones in which HGV traffic is particularly dense;
- regions subject to frequent rain and fog.
# TEST BANDES SONORES 91 : QUESTIONNAIRE

<table>
<thead>
<tr>
<th>Q4 NOM CONDUCTEUR</th>
<th>Q8 DE JOUR, DIRECTION LUMIERE</th>
<th>Q9 ETAT DE LA CHAUSSÉE</th>
<th>Q12 VENTILATION/CHAUFFAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q7 LUMINOSITÉ/VISIBILITÉ</td>
<td>Q8 DE JOUR, DIRECTION LUMIERE</td>
<td>Q9 ETAT DE LA CHAUSSÉE</td>
<td></td>
</tr>
<tr>
<td>Nuit noire</td>
<td>Diffuse</td>
<td>Sèche</td>
<td></td>
</tr>
<tr>
<td>Nuit claire</td>
<td>De dos</td>
<td>Humide</td>
<td></td>
</tr>
<tr>
<td>Petit jour</td>
<td>De face</td>
<td>Nouillée</td>
<td></td>
</tr>
<tr>
<td>Brouillard/brume</td>
<td>De côté gauche</td>
<td>Provoque gerbe d’eau</td>
<td></td>
</tr>
<tr>
<td>Temps couvert</td>
<td>De côté droit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumière moyenne</td>
<td>Verticale/dessus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grande luminosité</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Q10 VITRES/TOIT DU VÉHICULE</th>
<th>Q11 AUTO-RADIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermés</td>
<td>Éteint</td>
</tr>
<tr>
<td>Ouverts</td>
<td>Allumé</td>
</tr>
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<table>
<thead>
<tr>
<th>Q13 VOTRE 1er CONTACT AVEC CETTE BANDE SONORE</th>
<th>Q14 DESCRIPTION DE LA BANDE SONORE (sans ralentir) :</th>
</tr>
</thead>
<tbody>
<tr>
<td>Je l’ai d’abord VUE</td>
<td>Vos impressions</td>
</tr>
<tr>
<td>Je l’ai d’abord ENTENDUE</td>
<td></td>
</tr>
<tr>
<td>J’ai d’abord senti les VIBRATIONS</td>
<td></td>
</tr>
<tr>
<td>Autres</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Q15 EFFET VISUEL / LIGNE BLANCHE HABITUELLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un peu plus visible</td>
</tr>
<tr>
<td>Similaire</td>
</tr>
<tr>
<td>Un peu moins visible</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q16 EFFET SONORE</th>
<th>Q17 EFFET DES VIBRATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trop important et insupportable</td>
<td>Trop importants et insupportables</td>
</tr>
<tr>
<td>Un peu trop important mais supportable</td>
<td>Un peu trop importants mais supportables</td>
</tr>
<tr>
<td>Suffisant et acceptable</td>
<td>Suffisants et acceptables</td>
</tr>
<tr>
<td>Pas assez audible</td>
<td>Trop peu perceptibles</td>
</tr>
<tr>
<td>Inaudible</td>
<td>Non perceptibles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q18 EFFICACITÉ GLOBALE</th>
<th>Q19 PARTICIPATION A LA SÉCURITÉ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trop efficace/génante</td>
<td>Très sécurisante</td>
</tr>
<tr>
<td>Un peu trop efficace/génante</td>
<td>sécurisante</td>
</tr>
<tr>
<td>Efficace</td>
<td>Moyennement sécurisante</td>
</tr>
<tr>
<td>Pas très efficace</td>
<td>Pas très sécurisante</td>
</tr>
<tr>
<td>Pas tout efficace</td>
<td>Insécurisante</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q20 NOTE SUR 10 DE LA BANDE SONORE : immédiate spontanée</th>
<th>Q21 RAISONS DE LA NOTATION</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

Note rectifiée après vos tests / 10
**TEST BANDES SONORES 91 : SIGNALETIQUE ROUTIER**

**ENQUETRICE/ENQUETEUR :**

**FICHE REMISE le ....../....../91**

**OPINION A PRIORI SUR LES BANDES SONORES :** Ne connais pas 1  
   Plutôt Bonne 2  
   Neutre - Aucune 3  
   Plutôt mauvaise 4

---

**LE VEHICULE :**

**ANNÉE de 1ère MISE EN CIRCULATION :** 19  

**CHARGE PTC :**

**IMMATRICULATION :**

**KILOMÉTRAGE :**

**TYPE & MARQUE :**

**DIRECTION ASSISTÉE :**

**SUSPENSION HYDROPONEUMATIQUE :**

**ÉQUIPEMENT SPÉCIAL DE SIEGE :**

**LE VOYAGE : TRAJET**

| Ville point de départ | date ....../....../91 | Heure .... |
| Ville point d'arrivée | date ....../....../91 | Heure .... |
| Ville point de retour | date ....../....../91 | Heure .... |

**LE CONDUCTEUR :**

<table>
<thead>
<tr>
<th>Nom</th>
<th>Prénom</th>
<th>Adresse</th>
<th>Code postal</th>
<th>Ville</th>
</tr>
</thead>
</table>

**SOCIÉTÉ :**

<table>
<thead>
<tr>
<th>Tel domicile</th>
<th>Tel</th>
</tr>
</thead>
</table>

**AGE :**

| 18-24 | 1 |
| 25-34 | 2 |
| 35-44 | 3 |
| 45-54 | 4 |
| 55-64 | 5 |
| 65 et + | 6 |

**SEXE :**

| Féminin | 1 |
| Masculin | 2 |

**CSP :**

| Salarié | 1 |
| Employeur | 2 |

**PROBLÈME ÉVENTUEL : DOS/VERTEBRES**

| non, aucun | 1 |
| peu important | 2 |
| assez important | 3 |

**PROBLèME ÉVENTUEL : DOUfE**

| non, aucun | 1 |
| peu important | 2 |
| assez important | 3 |

**Nombre de zones à tester :** Aller 1 2 3 4  
   Retour 1 2 3 4
ORGANIGRAMME DES TESTS COMPARATIFS

LÉGENDE :

- 0 à 33 tests comparatifs effectués
- 34 à 66 tests
- 67 et +
1 - Les marquages visibles la nuit par temps de pluie - LCPC - Mlle SERRES (RGRA) 1987

2 - Signalisation horizontale - Marquages en reliefs - Campagne expérimentale bruit-vibration sur le CD 302 - CETE de l'Est - MM SOULAGE et HATTÉL - mars 1990 (ASSECAR)

3 - Marquages de chaussées visibles la nuit par temps de pluie - Mesure de luminance rétrofréchie (R1) - CETE Nord-Picardie - M. KRAUZE - 1991 (ASSECAR)

4 - Signalisation horizontale - Marquages à protubérances - Expérimentation A 31 - SAPRR - MM FABRE et COUTOULY - 1988

5 - Evaluation des marquages à protubérances - Analyse des débords sur BAU d'autoroute pour observation avant/après - CETE de Normandie - MM FILLASTRE et VIOLETTE - avril 1991 (ASSECAR)

6 - Contrôle de la hauteur des marquages à protubérances sur autoroutes - CETE de l'Est - M. GUILLARD - 1991 (ASSECAR)

7 - Enquête vidéo-interview - Bandes sonores A 31 - CERC MARKETING - M. G. MILLIER - juin 1990 (ASSECAR)

8 - Sondage téléphonique - Découverte des bandes sonores - CERC MARKETING - M. G. MILLIER - juin 1990 (ASSECAR)


Nota : Ces documents sont disponibles à l'ASSECAR
SPOKE INJURIES

Epidemiology, causes and prevention of bicyclewheel entanglements

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Abstract

The results of an indepth research into injuries due to bicyclewheel entanglements in order to recommend effective prevention methods are given. The first part describes the results of a study into literature regarding spoke related injuries and preventive measures. In the second part epidemiological data regarding spoke injuries are given. The third part describes the results of an inquiry into spoke injuries involving children by mailing questionnaires to parents of victims of bicyclewheel entanglements under thirteen years of age that were recorded by the Dutch home and leisure accidents surveillance system (PORS) in 1988.

It appeared that nearly all victims were passengers (98%). Only 2% of the victims were cycling themselves. All the passenger victims were injured by entanglement of a foot or ankle between the spokes. Most of them were sitting behind the saddle. More than half of them in a seat or having footrests.

It appeared that none of the involved seats and most of the involved bicycle wheels were supplied with wheel spoke covers or overcoat guards. The common overcoat guards appeared to be too frail to guarantee effective protection. Parents are not sufficiently aware of spoke injury risks nor do they have adequate knowhow to avoid this risk. It is recommended to develop safety criteria for effective spoke guards for bicycle wheels and seats combined with an information campaign to parents how to prevent spoke injuries.

Introduction

From research into bicycle related accident (Kortstra & Harmsen, 1987) it appeared that the number of patients visiting A & E departments of hospitals for treatment of injuries due to bicycle related accidents in which no other vehicles are involved can be estimated at 40,000 a year in the Netherlands. About 11% of the injuries (4500) are due to entanglement in bicycle wheels. In 10% of the cases a part of the victim's body is entangled, and in 1% of the cases an object is entangled between the wheelspokes. In an accident caused by entanglement of an object in the wheelspokes mostly the cyclist falls down and gets injured. Most victims of spoke related injuries are small children. Moreover spoke injuries are the most frequently occurring bicycle related accident in this age group.

As no further details were available about the accidents and the way they happened in order to be able to recommend effective prevention measures the Consumer Safety Institute decided to carry out a study into the bicycle wheelspoke related accidents happening to children. The aim of the study was to identify the product related and non product related factors that both play a role in the cause of these accidents and are appropriate for tackling by preventive measures and also to define appropriate measures in order to prevent these injuries.
The study can be divided into three parts. First the literature concerning bicycle and spoke related injuries and safety measures to prevent spoke related accidents and injuries (legislation measures, safety standards, education materials). In the second part the data concerning spoke related injuries from the national home and leisure surveillance system (PORS) are analyzed. Thirdly an inquiry into spoke related accident was carried out by mailing questionnaires the parents of spoke injury victims under thirteen years of age recorded by PORS in 1988 in order to obtain the lacking indeth information regarding accident factors that was needed to recommend adequate preventive measures.

Study of literature

The literature was studied in order to obtain data regarding factors that cause spoke related injuries as well as data regarding adequate measures to prevent these accidents. All injuries caused by accidents where bicycle wheelspokes were involved were regarded as spoke injuries. The available literature sources concerning spoke injuries mostly referred to bicycle accident research on a local or regional base. Only a few studies were nationwide. A number of studies were limited to injuries caused by spokes in certain age groups, mostly young children.

From the study of literature it appeared that injuries due to entrapment in a bicycle wheel is a substantial problem not only in the Netherlands, but also in several other western countries as Sweden (Björnstig, 1984), U.S.A. (CPSC, 1973; Davis, 1980; Kravitz, 1977; Waller, 1985; Selbst, 1987; Betz, 1983), Germany (Drewes, 1965), Denmark (Mogenson, 1984), Finland (Viljanto, 1975), Israel (Roffman, 1980), South Africa (Gonski, 1970), Australia (Grundill, 1986).

According to one author (Waller, 1985) spoke injuries were the most frequently occurring product related bicycle accident. The results of the different studies in different were globally speaking comparable to each other. The victims were mostly small children transported as a passenger on an bicycle. The sustained injuries were mostly fractures, wounds, distorsions and contusions to foot, ankle or lower part of the leg.

In only one study (Björnstig, 1984) less than half of the victims were passengers and more than half of the victims were cyclists. In other studies only a minor part of the victims were cyclists who mostly got entangled with their foot or hand in the bicycle wheel (CPSC, 1973; Davis, 1980; Kravitz, 1977). In case an object was entangled the victims mostly fell from or with their bicycle due to the obstruction of the wheel, mostly by a bag or bicycle parts such as brakeblocks and cables, dynamos and locks (Davis, 1980; Björnstig, 1984; CPSC, 1973; Kravitz, 1977).

The lack of spoke guards on the bicycle wheels appeared to be a very important product accident related factor. As far as this aspect was included in the study all bicycles involved in spoke injuries were not equipped with spoke guards on the wheels (Björnstig, 1984; Drewes, 1965).

Drewes (1965) critisized nets used as coatguards on bicycles in Germany also as not being adequate to prevent spoke injuries. The second factor was the unsafe condition of the bicycle mostly due to bad maintenance such as broken, not working or worn out brakes, brake blocks, slippery pedals (CPSC, 1973; Björnstig, 1984; Davis, 1980; Kravitz, 1977; Mogensen, 1984). Loose parts, especially brake cables, bicycle locks and dynamos appeared to be a real danger for spoke related injuries as they lock the wheel when they are entangled. This makes it more difficult for the cyclist
to keep his bicycle under control and to keep his balance, while loosing his balance the cyclist's or passenger's foot can be entangled in the wheel.

Almost no data regarding the relation between injuries and the use of bicycle seats, its design and spoke injuries were found. As far as this aspect was included in the study it appeared that mostly passengers behind the saddle were involved in spoke injuries. Some of these victims were sitting in a bicycle seat and some were not (CPSC, 1973; Kravitz, 1977). Drewes (1965) mentioned that all passengers entrapped in the front wheel were transpoted in a seat in front of the saddle.

Regarding the non-product related factors the transportation of passenger appeared to be the most important factor (Kravitz, Betz, Davis, Björnstig, Waller). Some authors explained this fact by pointing out that passengers have many more difficulties to keep their balance than the cyclists themselves. It is almost impossible for passengers to keep their balance without using their legs and therefore it is very difficult for them to avoid to come in touch with the wheel. As small children do not have the same skill as adults have to keep control over their body and to keep their balance, they are especially at risk for spoke injuries (Roffman, 1980).

Other non product related factors that could be traced were uncareful cycling which leads to imbalance of bicycle, cyclist or passenger (CPSC), lack of know-how regarding causes and prevention of spoke injuries (Mogenson, Roffman), lack of experience of the passenger how to behave as a passenger (Roffman), the transportation of bags on the bicycle (Björnstig).

Besides that it was found that having bare feet for cyclist or passenger means a greater risk of serious injuries in case of an accident (Kravitz, 1977).

The preventive measures recommended by the authors were largely comparable too. As far as preventive measures were recommended in all cases the importance of adequate spoke guards to prevent contact between passengers and spokes was emphasized (Betz, Drewes, Kravitz, Roffman, Viljanto). One author (Björnstig, 1984) recommended a regulation requiring spoke guards at both bicycle wheels in order to prevent all spoke related injuries of passengers and cyclists. Regarding the transportation of small children most authors recommended the use of bicycle seats well fitted for the child supplied with adjustable foot seats and adequate spoke guards (Betz, Björnstig, Kravitz, Viljanto).

In the current regulations and standards concerning bicycles in the Netherlands no attention is paid to the prevention of spoke injuries (V & W, 1988; ISO 1982). In Germany and Denmark national standards are already developed for bicycle seats requiring adequate spoke guards for both wheels. Only information materials concerning bicycle seats in the Netherlands pay attention to the prevention of spoke injuries, as they emphasize the importance of adequate spoke guards as a necessary part of the seat or bicycle (ANWB, 1983; SCV, z.j.; Stichting Fiets, 1980). Besides that the TNO Road-Vehicle Institute developed safety criteria for bicycle seats requiring spoke guards for seats behind the saddle as a basis for certification (IW-TNO, z.j.).

Epidemiological data

In this section the data regarding spoke related injuries from the Dutch home and leisure accident surveillance system (PORS) are analyzed.
PORS records all home and leisure accidents whose victims go for treatment to A & E department of 14 hospitals. These 14 hospitals contribute a representative sample from the 140 general and university teaching hospitals which have an Accident and Emergency department with a 24 hour service. The sample is stratified according to size of hospital (number of beds) and a level of urbanization of the town (city in which the patient lives). On the basis of their recording system PORS national figures can be estimated.

During 1984 through 1988 successively 472, 442, 473, 499 and 490 injuries due to entrapment in bicycle wheels were recorded. This means that almost 4500 victims are visiting A & E department for treatment of spoke related injuries annually.

Figure 1  Number of spoke related injuries by age of the victims. The third column represents the sex rate and the fourth column the number of accidents per 100,000 of the average Dutch population (Source PORS 1984 through 1988, CBS 1987)

<table>
<thead>
<tr>
<th>Age in years</th>
<th>Number</th>
<th>Perc.</th>
<th>Sexrate</th>
<th>Incidence per 100,000 of the population</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>89</td>
<td>3.7</td>
<td>0.8</td>
<td>49</td>
</tr>
<tr>
<td>2</td>
<td>319</td>
<td>13.4</td>
<td>1.1</td>
<td>364</td>
</tr>
<tr>
<td>3</td>
<td>429</td>
<td>18.1</td>
<td>1.0</td>
<td>502</td>
</tr>
<tr>
<td>4</td>
<td>504</td>
<td>21.2</td>
<td>1.0</td>
<td>584</td>
</tr>
<tr>
<td>5</td>
<td>317</td>
<td>13.3</td>
<td>0.9</td>
<td>354</td>
</tr>
<tr>
<td>6</td>
<td>165</td>
<td>6.9</td>
<td>1.0</td>
<td>181</td>
</tr>
<tr>
<td>7-9</td>
<td>174</td>
<td>7.3</td>
<td>1.3</td>
<td>66</td>
</tr>
<tr>
<td>10-12</td>
<td>68</td>
<td>2.9</td>
<td>1.0</td>
<td>25</td>
</tr>
<tr>
<td>13-14</td>
<td>67</td>
<td>2.8</td>
<td>1.1</td>
<td>32</td>
</tr>
<tr>
<td>15-19</td>
<td>106</td>
<td>4.5</td>
<td>0.9</td>
<td>17</td>
</tr>
<tr>
<td>20-34</td>
<td>84</td>
<td>3.5</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>35+</td>
<td>51</td>
<td>2.1</td>
<td>0.8</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td>3</td>
<td>0.1</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>2376</td>
<td>100.0</td>
<td>1.0</td>
<td>33</td>
</tr>
</tbody>
</table>

* Because of rounding of the number they do not add up exactly to 100.0

Figure 1 shows that the age group 2 through 5 years is comparatively most at risk to become a victim of spoke related injuries. Within this age group three and four year old children are more involved in spoke injuries than two and 5 year old children.

Regarding the sex rate of the victims it appeared that the victims showed an equal segmentation, also in most of the different age groups.

Regarding the nature of injury it appeared that the victims most frequently sustained wounds of the ankle (18%) contusion of the ankle (14%), contusion of the foot (14%) and wounds of the foot (13%). Besides that, ankle distortions (8%), fractures of the lower part of the leg (6%) and ankle fractures (6%) frequently occurred. Two to four year old victims sustained more fractures in the lower part of the leg compared with victims of 7 or more years old. Victims of 10 years or more sustained comparatively more other injuries, mostly hand injuries.
From the recorded accident descriptions could be distilled that in 97% of the cases a part of the victims' body was entrapped between the spokes of a bicycle wheel. In 94% of the cases a foot or ankle, in 3% of the cases a hand and in also 3% of the cases an object, mostly a bag. The description of the accidents was mostly limited to "hand or foot between wheelspokes" without any other information. The descriptions that gave more information indicate, that in most of the cases the entanglement occurred during cycling. In a few cases the victim got entangled with hand or foot while he was repairing the bicycle.

Admission to hospital

About 250 spoke injury victims are annually admitted to hospital (4.6%). Compared to the 3.6% admission of all victims recorded by PORS, this admission rate is slightly higher. However, compared to the 5.6% admission rate of all two to six years old children recorded by PORS, the admission rate is almost the same.

The number of days the admitted victims stayed in hospital varied from 1 to 34 days with an average of 9 days. This is less than the average length of admittance for all inpatient victims under 65 years old of age recorded by PORS (11 days). This means that injuries due to entrapment in bicycle wheels are slightly less severe than injuries due to the other accidents recorded by PORS.

Inquiry

As the analysis of the statistical data concerning spoke injuries gave almost no information about the accident factors it was decided to carry out an inquiry into the victims of spoke injuries under 13 years old of age. This inquiry took place in 1989 by mailing questionnaires to the parents of the victims under 13 years of age who were recorded by PORS from the first of January 1988 through February 28th 1989.

The items of the questionnaire were based on the results of the literature study. Most questions were precoded. The questionnaire was sent to 502 persons of whom 289 were adequately filled out to be analyzed (58% response). To interpret the results it has to be considered firstly that they only account for spoke injuries where children under thirteen years of age are involved. And secondly that the victims over 6 years of age were underrepresented in the response group. This correlates probably with the difference in the segmentation into nature of inquiry. The inquiry results show an overrepresentation of fractures in the lower part of the leg (13%, PORS: 7%) and an underrepresentation of other injuries (5%, PORS: 12%).

Results

Regarding the question "was the victim passenger or cyclist" it appeared that in 282 (98%) of the 289 inquired cases the victim was sitting as a passenger on the bicycle. Only 6 victims (2%) were cycling themselves at the moment of the accident and in 1 case this was unknown.

There were no cycling victims under 5 years of age. In almost every case the victim's foot was entrapped between the wheelspokes. This happened to all the passenger victims and to 4 of the cycling victims (67%). Only two cases were different. In one case the cyclist's hand was entrapped and in one case a
plastic bag entrapped and the cyclist fell with his bicycle. Each two out of three entrapments caused a foot or ankle contusion, in each one out of five entrapments the lower part of the leg, foot or ankle was fractured. The way the passenger victims were transported on the bicycle is shown in figure 2.

Figure 2  Passenger victims entrapped in a bicycle wheel to the place on the bicycle and use of bicycle seats

<table>
<thead>
<tr>
<th>Place on the bicycle</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behind the saddle</td>
<td>265</td>
<td>94</td>
</tr>
<tr>
<td>- in a seat</td>
<td>78</td>
<td>28</td>
</tr>
<tr>
<td>- not in a seat</td>
<td>185</td>
<td>65</td>
</tr>
<tr>
<td>- unknown</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>In front of the saddle</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>- in a seat</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>- on the bar of a bicycle for males</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>- other</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>282</td>
<td>100</td>
</tr>
</tbody>
</table>

More than 9 out of every 10 passenger victims were sitting behind the saddle (94%), 6% sat in front of the saddle. Each one out of every three was transported in a bicycle seat. Almost a third of the passenger victims sitting behind the saddle (29%) were transported in a special bicycle seat and two thirds of the passenger victims in front of the saddle (67%) were transported in a special bicycle seat. The others in front of the saddle were sitting on the bar of a bicycle for males. One victim was transported otherwise.

The victims transported not in a seat behind the saddle were all sitting on the carrier. A substantial part of them (80, 43%) were provided with back and footrests or one of these supports. From them 60 (32%) were provided with back- and foot rests, 15 (8%) only with foot rests and 5 (3%) with a back seat only. More than half (105, 57%) of the victims on the carrier were not provided at all with any of these supports.

The respondents mentioned different reasons why the victim was not transported in a seat. The reason most frequently given was that the victim was too old for a seat (40%), "No seat available" (14%), "The use of another bicycle" (13%), "Transportation on a bicycle for children" (11%), and "Victim refused to sit in a seat" (5%) were other frequently mentioned reasons.

Comparing the place on the bicycle and use of seats with the age of the victims it appeared that victims transported behind the saddle not in a seat showed the greatest variety in age (from 0 to 12 years). The age of victims in a seat behind the saddle varied from 1 to 6 years. Victims in a seat in front of the saddle were two to five years and those on the bar three to six years of age.
Type of seats involved

Regarding the type of the seats involved it appeared that all were equipped with a back rest and most of them with arm- and foot rests. Two third of the seats positioned behind the saddle had foot rests, 80% had arm rests. The seats in front of the saddle were all equipped with back-, arm- and foot rests. None of the involved seats was equipped with any kind of guards to protect the passenger's legs from touching the wheel spokes.

Age of the cyclist and type of the bicycle

Regarding the age of the cyclists transporting the victims on a bicycle and the type of bicycle involved, it appeared that most of them were adults using a common bicycle for adults. The victims in a seat were all transported by adults and all but two cases they used a common bicycle for adults. In the other two cases a racing bicycle was involved. One in each four victims not in seat were transported by cyclists younger than 20 years of age. In 7% of the cases they were younger than 10 years. In 155 cases (84%) a common bicycle for adults were involved, in 11% of the cases bicycles for children were involved and in 2% of the cases the involved bicycle was of a so called folding type. The involved bicycles equipped with back- or footrests were in all except one case of the common type designed for adults. In the cases victims were transported in front of the saddle all but one of the cyclists were adults. In more than half of the cases a common bike for adults was used. The victims not in the seat were all transported by their father on a common bicycle for males. In one case a racing bicycle was used.

The presence of coatguards

Most involved bicycles were not equipped with overcoat guards or with broken or only one coatguard. Only at 20% of the involved bicycles, both coatguards were present and unbroken. The coatguards were all fitted on the back wheel. The proportion of bicycles equipped with two unbroken coatguards was the highest for the bicycles equipped with foot rests for the passenger (45%). For the bicycles with seats and for the bicycles for children this proportion was respectively 13% and 11%. None of the bicycles involved in injuries to the cyclist was equipped with coatguards.

Part of the wheel involved

Regarding the part of the wheel the entrapment took place it appeared that in most cases the foot or ankle was entrapped in the upper part of the back wheel. The victims transported in a seat showed the highest proportion of entrapments in the upper part of the wheel (85%).

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The figure shows that almost three out of every entrapment in the back wheel took place in part A + B of the wheel, which is the part that can be covered by coatguards of the usual size. This counts for 92% of the victims in a seat and for 66% of the victims not in a seat. The victims not in a seat on the carrier showed the highest proportion of entrapments in the back part (C) of the wheel. Compared with the position of the victims it appeared that nearly all victims sitting in the other way round position (21%, 84%) were entrapped in the back part (C) of the wheel. The proportion of entrapment in the back part was much smaller in the group of victims having a leg at both sides of the wheel (21%) and victims having both legs at one side of the wheel (27%).

In more than 90% of the cases the victim did not fall down from the bicycle. The victims who fell from the bicycle after being entangled were mostly sitting in a seat. The victims who fell before being entangled were mostly not provided with a seat.
Product failure

Less than 1% of the accidents was induced by failure of the seats or foot rests. In two cases the seat broke. In one case a foot rest snapped off the seat, in the other case it was not clear what part was broken.

In the entrapments not only bicycles without undamaged coatguards were involved. In at least 10% of the cases the coatguard broke during the accident. Mostly it was kicked into pieces by the victim's foot. As no attention was paid to this aspect in the questionnaire, this percentage must be considered as a minimum. The respondents mentioned the breaking of a coatguard in their answer to the question about special circumstances causing the accident.

Position of the victim

At the moment the victims were injured their position on the bicycle was mostly normal. The victims not sitting in a seat on the carrier showed the highest proportion of abnormal position during the ride (22%). Sitting in the other way round position did 14% and 8% were sitting with both legs at one side of the wheel. It appeared that two third of the victims in the wrong way round position sustained a fracture of the under part of the leg. This percentage is very high compared with the other victims.

Passenger's experience

It appeared that a third of the victims was injured during the first time he were transported on a bicycle in the way they were at the moment of the accident. This proportion was much higher among the victims sitting not in a seat on the carrier (39%) than among the victims in a seat on the carrier (19%).

More than one passenger on the bicycle

Another probable risk increasing factor was the transportation of more than one child at the same time. It was found that in 16% of the cases more than one child was transported on the bicycle. In 10% of the cases the victim was sitting in a seat on the carrier a second child was transported in front of the saddle and in 20% of the cases the victim was sitting on the carrier not in a seat a second child was transported either in front of the saddle (13%) or also on the carrier (7%).

Cause of injury according to the parents

According to the parents the entrapment was mostly caused by the lack of coatguards. Each one out of five parents mentioned this as the cause. Almost each one out of four (23%) mentioned the moving of the child at the moment the accident occurred and in two out of every three of these cases they pointed this as the cause. Other frequently mentioned causes were victim's foot slipped of the foot rest (9%) and bicycle made an unexpected move due to example driving in a curve or in a bump or hole in the path way. Regarding the injuries to victims in a seat at the handle bar a too short distance between handlebar and front wheel was pointed out as a cause of entrapment.
Prevention measures by the parents

After the injury most parents did something to prevent entrapments in the future. Mostly they fitted coatguards on the back wheel. So did three out of every four parents of victims transported in a seat on the carrier and one out of four parents transported or the carrier without seat. Each one out of five of them bought a seat for their child. Regarding the prevention of entrapments in the front wheel each one out of four parents decided to transport their child only in a seat behind the saddle. Some parents left the prevention by warning the child.

Conclusions

It can be concluded that the most important non-product related factor in injuries to children due to entanglement in bicycle wheels is being transported as a passenger on a bicycle. This risk applies not only to children transported behind the saddle but also to children transported in front of the saddle, both in a seat as well as not in a seat.

Another important non-product related factor is the lack of the parent's knowledge regarding the risk of entrapment and know-how to prevent this risk. This conclusion can be based on the fact that in a number of cases adequate measures were taken after the injury had occurred and in other cases no measures or inadequate measures were taken. Other non-product related factors are not using bicycle seats for transport of a child, transporting more than one passenger on the bicycle, the other way round position of the passenger and lack of experience in being transported as a passenger.

The most important product related factor is the lack of guards preventing contact with the wheelspokes. This conclusion is based on the following results of the study:
- 80% of the injuries bicycles not supplied with unbroken coatguards were involved
- None of the involved bicycle seats was designed with any kind of guards preventing contact between foot or leg and the bicycle wheel

The second product related factor is the inadequate protection of coatguards against the risk of entrapment of the passenger's foot. The strength of the material appears to be too little as well as the size of the product too small to guarantee adequate protection.

Speaking in terms of prevention, it can be estimated that 70% of the injuries could have been prevented by using bicycles equipped with coatguards of adequate strength by using bicycle seats equipped with spoke guards instead of the involved bicycle seats. 31% of the injuries could have been prevented. By combining these two measures the number of injuries could have been reduced by 80%.

To prevent the remaining 20% injuries other measures have to be taken, such as spoke guards on the front wheel and coatguards of a bigger size on the back wheel.

Recommendations

Based on the results of the study the following recommendations have been made:
- the government should take measures to improve the safety of bicycles and
bicycle seats, especially in relation to the safety of transportation of children on a bicycle.
- the national standard organization in the Netherlands should start standardization activities aimed at the prevention of bicycle wheel entanglements by developing standards for coat- and spoke guards and for bicycle seats for children including requirements concerning adequate guard of wheelspokes.
- The trade and industry should only produce and sell safe bicycles, bicycle seats and coatguards supplied with adequate information regarding safe use and maintenance.
- consumer education organizations should educate the parents about the risk of bicycle wheel entanglements and advise them how to avoid this risk.

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COLLISIONS AND INJURIES
ANALYSIS OF RECENT TRENDS IN BUS AND COACH SAFETY IN BRITAIN

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Transport Studies Group
University of Westminster

and Dr Nicholas Tyler
Transport Studies Group
University College London

Abstract

We examine in detail trends from 1966 to 1990 and the fitting of statistical models to assess whether significant changes have taken place in casualty rates since local bus deregulation in 1986.

The major source of data is the 'Stats 19' collated from police reports by the Department of Transport.

The evidence indicates that no significant change in casualty rates for bus and coach occupants (defined as those killed or seriously injured) has occurred since local bus deregulation, although the previous trend of reduction in fatality rates has not been maintained.

International comparisons have been made between Britain and a sample of other West European countries. Britain appears to have a higher occupant fatality rate. However, other countries' data do not always include casualties to bus and coach occupants other than those in which vehicular collisions occur. Better comparative data is available for accidents involving buses and coaches with other road users, notably for Britain and Germany. These suggest that such accidents tend to reflect the national pattern of road casualty rates - for example, Germany has a higher level of collisions between buses and coaches, and other road vehicles, while Britain has a relatively high incidence of casualties involving pedestrians.

Differences in accident rates between Britain and other European countries and the extent to which they reflect real differences, as distinct from those due to differences in recording of data, will be evaluated, along with policy implications.
1. Definitions

Definitions employed follow those used in conventional British practice, based on the 'Stats 19' data collected through local police forces by the Department of Transport. For each accident, data are obtained on all casualties, vehicle type, time of day, road type, etc. which may be cross-tabulated. In this paper we make use both of published data, and special tabulations purchased for this purpose.

An 'Accident' is an event in which one or more persons is killed or injured. Damage-only accidents are not considered in our work. An 'accident' could thus range from a major event such as a high-speed coach crash on a motorway, in which many people are killed or injured, to a single passenger being slightly injured in an event not involving any other people. In Section 3 we are concerned only with bus and coach occupants, but enlarge the scope to cover other road users in Section 4. 'Fatal', 'Serious injury' and 'Slight injury' are as defined in 'Road Accidents Great Britain'. In addition, 'Killed and Seriously Injured' (KSI) is combined category, often used in safety analysis to give a more robust trend than that based on fatalities alone, which varies markedly from year to year.

'Buses and Coaches' are vehicles defined as such by their appearance and construction - usually of 16 seats upwards, and including all types of service (local, express, tour, contract, etc.). The definition is similar to, but not identical with, the legal term 'public service vehicle' (psv) being a vehicle used for public hire or reward, either as a whole or at separate fares, licensed to carry over 8 passengers. 'Bus and coach occupants' are people in a bus or coach at the time of an accident, including passengers, drivers and conductors.

2. Recent Trends in Britain

It can be argued that bus and coach accidents are a very minor problem. In Britain, for example, fatalities to bus and coach passengers have averaged only 15 to 20 per year in most recent years, compared with total road user facilities of around 5,000 per year, although rising to 25 in 1991 (Department of Transport, 1992). However, public transport accidents often attract far more attention than such objective data suggests, either because of individual
accidents in which many casualties occur (such as major coach crashes), or the feeling that a greater responsibility applies to the operator of a public service than to individuals using the roads at their own risk.

We have examined trends in bus and coach occupant casualties from 1966 to 1990 inclusive. Data for casualties by type; bus and coach vehicle-kilometres, and bus and coach passenger-kilometres, are shown in table 1, highlighting trends at five-year intervals.

During this period the absolute total of casualties has dropped very substantially. Fatalities ranged between 50 and 106 per year during the 1970s, but only 14 and 35 during the 1980s, although certain years were influenced by major coach crashes in which many casualties occurred. 'KSI' casualties have likewise declined from over 1,600 per year in the mid-1970s to under 1,000 in the late 1980s and total casualties from about 14,000 per year in the early 1970s to around 10,000 per year.

These reductions are of course influenced by the decline in use of bus and coach services, from 62,000 million passenger-kilometres in 1966 to 41,000 in 1990. Vehicle-kilometres, however, rose in the 1980s to give a very similar figure in 1990 (3,838 million) to 1966 (3,708 million). This was a result of rapid growth in local bus service kilometres from deregulation of that sector in October 1986. However, total passenger trips (for all types of service) fell by 50% between 1966 and 1990. Despite a rising average trip length, average occupancy levels have fallen substantially, from around 17 passengers in 1966, and to around 11 passengers in 1990. Local bus passenger trips in particular, have fallen sharply since deregulation - by 14% between 1985/6 and 1990/1 (Department of Transport, 1991a), despite the growth in service kilometres.

The method of estimating the national total passenger-kilometres is a rather crude one, and data are estimated to only the nearest 1,000 million units. The apparent stability of this figure since 1986 may seem surprising in view of the marked decline in local bus traffic but results from a growth in 'non-local' bus and coach travel (express, tour etc.) which offsets decline in the shorter local trips.
Table 1 Five-year trends in bus and coach occupant casualties, the volume of service, and ridership.

<table>
<thead>
<tr>
<th>Year</th>
<th>Fatalities</th>
<th>KSI</th>
<th>Vehicle Km (Million)</th>
<th>Passenger Km (Million)</th>
<th>Passenger Trips (Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>76</td>
<td>2,161</td>
<td>3,708</td>
<td>62,000</td>
<td>11,028</td>
</tr>
<tr>
<td>1970</td>
<td>74</td>
<td>1,924</td>
<td>3,461</td>
<td>56,000</td>
<td>9,154</td>
</tr>
<tr>
<td>1975</td>
<td>115</td>
<td>1,650</td>
<td>3,550</td>
<td>54,000</td>
<td>8,168</td>
</tr>
<tr>
<td>1980</td>
<td>29</td>
<td>1,952</td>
<td>3,338</td>
<td>45,000</td>
<td>6,783</td>
</tr>
<tr>
<td>1985</td>
<td>32</td>
<td>1,036</td>
<td>3,323</td>
<td>42,000</td>
<td>6,178</td>
</tr>
<tr>
<td>1990</td>
<td>19</td>
<td>826</td>
<td>3,838*</td>
<td>41,000</td>
<td>5,470*</td>
</tr>
<tr>
<td>1991</td>
<td>25</td>
<td>725</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

*Provisional Figures, 1990/1 data.

Department of Transport (1991a), (1991b), (1992) and (annual).

In estimating overall occupant casualties, total passenger-kilometres is probably the most valid indication of exposure to risk. However, the substantial element of 'boarding and alighting' casualties (see Section 3.3) is clearly a function of trips as such. The incidence of collisions with other road users (Section 3.5) is a function of the total kilometres run by buses and coaches, and traffic density on roads over which they are operated.

The most realistic method of representing the casualty rate is probably that of 'killed and seriously injured per 1,000 million passenger-kilometres' (subject to the qualifications expressed above), as shown in Figure 1. The model was calibrated on data for 1966 to 1985. It can be seen that the observed rates since deregulation lie close to the projected trend line, and within the 95% confidence interval represented by the upper and lower lines. A similar conclusion, that no significant change has occurred in accident rates since local bus deregulation, is also supported in other recent studies (Astrop et al, 1991).
Figure 1: Observations and a simple linear model describing the trend of bus and coach passenger casualties (killed and seriously injured) from 1966 to 1990.

The model for the trend shown is:

\[ KSI \text{ per 1,000m pax-km} = 34.10 - 0.80t \] (1)

in which \( t \) represents the years from 1966. The coefficient of determination \( (r^2) \) is 0.52. It should be noted, however, that there is only one independent variable in the model. Extrapolated over a long period, this model would be unrealistic, as the same absolute reduction in the casualty rate per year is implied. An alternative model was therefore calibrated on data from 1966 to 1985, as illustrated in Figure 2.

\[ KSI = \exp (5.865 + 0.0285k - 0.0168t) \] (2)

in which \( t \) is defined as above and \( k \) represents passenger kilometres per year (thousand million). This produces a much better fit, with a coefficient of determination \( (r^2) \) of 0.94. The apparent stability in passenger-kilometres from 1986 to 1990, however, produces some bias (see comments above).
Figure 2: Killed and seriously injured passenger casualties as a function of time and passenger-kms.

3. Specific Aspects of British Trends

3.1. Local and Long-Distance Operations

The numbers of killed and seriously injured casualties for each year are also shown in Figure 3, where the location of the accident is divided between 'built-up' areas and 'non-built' up areas. It is reasonable to assume that the former category is mainly concerned with local bus operation, and that the latter includes express coach operation together with other types of coach operation, such as private hire: it is unfortunately not possible to distinguish between the various categories of operation from the published statistics. Figure 3 shows that the number of killed and seriously injured casualties in the non-built-up category has generally declined, but with peaks in 1975 and 1985, associated with specific major accidents. The casualties on built-up roads have shown a more consistent decline, although the absolute average per year is much higher than for the other type of service - a result of the difference in the number of kilometres travelled by local services in comparison with that for express and other interurban services, and the high incidence of boarding and alighting casualties in local services.
Figure 3: Killed and seriously injured bus and coach occupant casualties by road type.

3.2. Boarding and Alighting Casualties

About half of the killed and serious injury casualties in built-up areas are a result of passenger boarding and alighting accidents. As Figure 3 shows, they have declined in absolute terms since 1980, which matches the drop in total passenger trips, but still accounted for 40% of the total in 1990 as shown in Fig 4.

Figure 4: Killed and seriously injured casualties boarding and alighting, and all KSI injuries on passenger services in built-up areas from 1980 to 1989.
3.3 Casualty Rates and Age of Passenger

This was examined in detail in earlier work at the University of Westminster (Rogers et al. 1988) estimating casualty rates (all severities) by number of trips made, for the period 1980 to 1984 inclusive. For the age group 30-59 the casualty rate was very close to the mean for all passengers but that for those over 60 was some 56% higher, while for the 15-19 group the rate was only 30% of the average. In terms of absolute casualty numbers, Colski (1991) shows that in 1990, 40% of passenger casualties were aged 60 or over. Of these, 36% were standing at the time of the accident, and 23% boarding or alighting. This appears to support recent vehicle design policy initiatives by the Disabled Persons Transport Advisory Committee (DPTAC), which emphasise means such as improved positioning and design of handrails, reduced step heights, and clearer marking of step edges.

3.4 The Effect of Vehicle Design and Layout

An unusual feature of bus design in Britain, is the continued use of the open rear-platform double-decker, without any doors to regulate passenger movement, and with fares collected by a roving conductor. Most such remaining vehicles are of the 'Routemaster' type operated in central London. Police records in London and Greater Manchester were used to compare accident characteristics in greater detail than permitted by 'Stats 19' data (Rogers et al. 1988). Over the period 1985-1986, the average bus occupant casualty rate in London (KSI) was found to be up to ten times that found in Manchester whether measured on a basis of vehicle-km, or passenger trips. A much higher proportion of bus passenger casualties in London (62%) was associated with boarding or alighting, than in Manchester (28%).

It was clearly associated with the major role of the 'Routemaster' in London, which represented 64% of all boarding and alighting casualties, but only about 30% of bus-kilometres run. Many other London buses at that time were of the type with driver controlled centre exit doors, as well as an entrance directly adjacent to the driver. In contrast, most of the Manchester fleet were of a single (front) doorway design only. As a result of increased public concern about passengers trapped in centre-exit doors, new regulations now require that a more sensitive mechanism is fitted to detect such following some
fatalities following such accidents in London.
Ironically, no equivalent public concern is evident about
continued use of the much more dangerous ‘Routemaster’
layout, which is accepted as a customary feature of the
London transport system.

3.5 Accident Involvement Rates with Other Road Users

Most buses operate in urban areas with high densities of
other road traffic (including pedestrians and cyclists)
sharing the same road space. They are usually the largest
and heaviest vehicles (along with lorries) in such areas.
Hence in the event of a collision, much greater harm may
come to other road users as a result.

As Gordge (1989) has shown, for each bus or coach occupant
fatality, an average of 6.7 fatalities occurred to other
road users arising from accidents involving buses and
coaches, over the period 1981 to 1985. In 1990, this
ratio reached 10.8 (Colski 1991), some 47% of the other
road users killed being pedestrians. The number of other
road user fatalities in accidents involving buses and
coaches in 1990 was 206. This increase in the ratio
results entirely from the absolute reduction in bus and
coach occupant casualties (itself partly a consequence of
falling ridership), but absolute number of other road
user casualties is also influenced by the increase in bus
and coach vehicle-km (which would increase the
probability of collision with other road users, ceteris
paribus).

Note that these accident involvement rates do not imply
that the bus or coach was the cause of casualties to other
road users, or that its driver was at fault, but simply
show a statistical relationship.

3.6 Extent to which casualties are associated

An analysis was carried out, using special tabulations of
‘Stats19’ data from 1984 to 1989, to show the extent to
which accidents involving a particular level of severity
are associated. The great majority (95%) of the serious
injuries occurred in accidents not involving fatalities,
and 91% of the slight injuries occurred in accidents not
involving any other degree of casualty. It can thus be
seen that many casualties do not result from major
accidents but are likely to involve individual passengers.
Typically, these would include boarding and alighting
casualties and those arising from the passenger being thrown off balance within the vehicle.

4. COMPARISONS BETWEEN BRITAIN AND OTHER EUROPEAN COUNTRIES

As indicated in our earlier work (Rogers et al 1988) such comparisons are more difficult than may at first appear, since although detailed records are kept by other West European countries, definitions are not consistent with or as comprehensive as, the British 'Stats 19' form. Significant variations may occur even within the same country (e.g. the use of different report forms by the Police Nationale and the Gendarmerie in France). In particular, bus and coach occupant casualties tend to be recorded in relation to collisions involving the vehicle as such, and do not necessarily include individual boarding and alighting casualties, or those involving standing passengers. This has the effect of reducing the apparent number of occupant casualties in built-up areas.

The differences have been examined by Gordge (1989) together with differences in the fatal accident involvement rate (see Section 3.5). The Netherlands and Britain displayed a similar fatality rate for the other road users involved in accidents with buses and coaches in the period 1981-85, but a lower rate was found in Western Germany, despite the overall higher accident rate for road transport found in that country in comparison with Britain. The composition of such accidents also differs: in Britain the most frequent victims are pedestrians, whereas in West Germany and the Netherlands car occupants and pedal cyclists respectively were the largest categories. This may reflect the mix of traffic in such countries, and the typical accident problem - for example, Germany has a higher rate of accidents involving cars on non-built-up roads while Britain, despite its generally good road safety record in comparison with France or Germany, does have a bad pedestrian accident rate, especially that for children. These differences in accident characteristics among the West European countries may well be reflected in the priorities they place on different types of accident remedial measures, both at domestic and international levels.
5. CONCLUSIONS FOR POLICY

The British experience suggests that quantity and price deregulation need not result in any statistically significant change in casualty rates for bus and coach occupants, provided that strict ‘quality control’ is retained. This is achieved through the operator licensing system in which vehicle maintenance and safety standards are probably the most important criteria in the award and duration of the licence, and numbers of vehicles (discs) an operator is permitted to run.

The major problem in Britain relates to the continued operation of open-platform ‘Routemaster’ buses in London, with a much higher accident rate for occupants than other types. The accident involvement rate with other road access is also a cause for concern. Occupant casualties result mostly from numerous accidents involving individual passengers, rather than major collisions involving the bus or coach itself. Elderly passengers have much higher accident rates, especially for boarding and alighting. This suggests that measures, to improve vehicle design in terms of entry/exit layouts, interior layouts and in driving standards, may be more important than politically fashionable measures, such as fitting seat belts or increased ‘roll-over’ strength, which result from a small number of spectacular coach crashes.

Within Europe as a whole, one may question whether the standard 100 km/h speed limit to be imposed on coaches is necessarily based on firm statistical evidence, or represents the most urgent priority. Within Britain, it will hamper the role of a successful long-distance express coach network. Current European proposed standard specifications for urban buses will encourage multiple entry/exit doorways. While speeding-up total boarding and alighting movements, these may well increase overall accident rates. However, only the British data at present seems to fully include such passenger casualties. Greater consistency in recording of data is thus desirable to inform policy debates especially when common international standards are proposed.
ACKNOWLEDGEMENTS

Earlier work in this field was carried out at the University of Westminster (then known as the Polytechnic of Central London) by Catherine Rogers, under the supervision of Peter White, between 1986 and 1988 with the support of a grant from the Science and Engineering Research Council (SERC). Further analysis was carried out by Dr Nigel Dennis. Some issues, especially of international comparisons, were examined further in Richard Gordge's MSc project in 1982. Updating of overall trends was carried out by Nick Tyler, working as a visiting researcher, in 1991.

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INVESTIGATION ABOUT FRONTAL COLLISION BETWEEN LARGE DIMENSIONS VEHICLES AND CARS

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Abstract

Automobile vehicles general use, generates a wide number of traffic accidents with the consequent human lifes looses and the consequent social and economic impact. This has made to develope many investigation programms, which tend to solve (or at least palliate) this problem and to implant national and international rules which afect the vehicles design from the point of view of the active and pasive safety.

Despite of the long way gone through, a big number of posibilities of improvement and unsolved problems exist yet. This is the cases of frontal collisions between large dimensions vehicles and cars. This kind of accidents has ocasioned in Spain more than 2000 deads between 1988 and 1990 and a large number of injured people.

A long this paper, an stadistic analysis of this kind of accidents ocured in Spain during the last years is presented initially. Through this analysis the different variables which play a role in the accident, like masses, veloeities, number of victims and injured people, situation of the ocupants in the vehicle, type of vehicle, among others, are interrelated.

The statistic study is concluded with the presentation of a severity index which has been defined to compare the severity of different accidents in function of the consequences for the car ocupants. After that, and starting from the conclusions obtained in the statistic study, a computer programm is used to simulate the same accidents introducing in the large dimensions vehicles energy absorption elements and/or protective barriere which will prevent the car penetration under the industrial vehicle, bus or coach.

The program used is the SINRAT III which allows the simulation as well of the collision as of the post-collision movements and the introduction of every protective or energy absorber elements.

Finally some conclusions about the investigation are presented.

1. Introduction

The sistematic use of the automobile vehicles creates a parallel problematical about the traffic accidents, with loss of human lifes the consequent social impact. This has led to the development of multiple and extended reserching programms tending to solve (or mitigate at least), that problematical, in a technological way, and to implant, national and international rules about the design of these vehicle from the point of view of the passengers safety.

However this has been and is nowadays scorce; the attention paid to solve a similar problem, in the case of large dimensions vehicles (industrial vehicles, coaches, buses...)
That being evidently less in figures, takes to the same disastrous effects and, possibly, with a deeper social impact. In a period between the years 1988 and 1990, more than two thousand people lost their lives in accidents like the ones studied in this study.

In a European context, states as Hungary, Germany, Great Britain or Sweden and anothers, are developing from the middle 70s different technological researching lines in order to fix normatives that, affecting to the design of this vehicles, tend to get a better safety to the road circulation.

In this paper are shown some of the conclusions obtained by the Grupo de Ingeniería de Vehículos y Transportes (GIVET), in the study of this type of collisions. Initially it has been studied occurred in the last ten years, and afterwards the collisions are anallize in situ.

With all the data, it has been extracted conclusion which left quantify the value of the man variable, that take past, as weell as it let determine a severity index for this type of accidents.

2. Statistic study

The present study takes case of a very especific traffic accidents the frontal or frontal-lateral collisions between a car and a large dimensions vehicle (coach, truck, truck with trailer,...).

The data base used to store and after use of the data referred to these accidents, has been design to let an exhaustive stadistic study of the accidents of this type happened in the spanish roads, during 1988, 1989 and 1990.

This statistics try to quantify the severity of this type of accidents and its incidence, in relation with another types of accidents, in the total figure of dead people that every year is produced in the spanish roads.

Data source

The data source used for the statistics creation has been the Daily Mortal Accidents Report of the Dirección General de Tráfico (Dirección de Programas de Investigación de Accidentes), of the years 1988, 1989, 1990.

Results of the statistic study

In order to make the best estimation possible, it has been made the analysis of this type of accidents happened during 1988, 1989 and 1990. although in the sample in study only has been considered those accidents included in the Daily Mortal Accidents Report of the D.G.T., in which there was at last one mortal victim in the 24 hours inmediatly after the accident. Despite the gravity of this type of accident there are some of them without any mortal victim in the mentioned period, and although we don't know how many, we are undervalveing the number of collisions of this type that can produce and consequently the number of the ones that can be analyzed.

In the figure 1 it can be observed that the months of the year in which take place a larger number of accidents are June, August, and November. Monthly the average number of accidents is 45 in Spain, with a maximum peak in 53 and a minimum are in 30 accidents.
FRONTAL COLLISIONS
NUMBER OF ACCIDENTS BY MONTHS

Fig. 1. Number of accidents by months.

Annually occurs an average number of 516, 3 mortal accidents of this type (the total sample used in this statistics is of 1549 accidents). If we use the year 1989 as a reference, we can compare incidence of this type of accidents in the whole number of mortal accidents. During that year there were 555 mortal accidents of the type Frontal collision between industrial vehicle and car, against a total of 6051 mortal accidents, what suposes the 9'17% of the total mortal accidents however, the incidence of these accidents in the number of deads was larger, as in these 555 accident there were a total of 802 mortal victims, what is the 11,15% of the total victims, and this can make us realize of the aggressivity or this type of accidents.

As it covered foreseen weekly all this type of accidents take place in national roads with double direction circulation. This type of roads are just the ones where the main part of the heavy traffic of goods transport between the different spanish regions, and where there are more probability of invasion of the circulation double direction lane from the opposite direction, either during overtakings, or one to speed excess, or different causes which will be analyzed after.
In local or comarcal roads exist also that probability, but the number of accidents is notably lower, due to the less heavy traffic that exist by those roads.

We have to consider two facts when we analyse the data corresponding to the distribution by ages of the heavy vehicle drivers implicated in this type of accidents. Inside the first group, from 18 to 25 years, the ages group is reduced due to the minimum period of experience required to obtain a drives licence for certain type of heavy vehicles once they have driver licences adecuated to vehicles with inferior dimensions. That makes impossible to a person of 19 or 20 years obtain this licence. Therefose is less probably find in the roads profesionals included in this group of uses than another groups.

On the other hand, the usual retirement age is 65 years, so it’s not very probably to find a profesionional driver over that age.

**Fig. 2. Heavy vehicle driver's age.**

Considering these two factors it is observed than the younger the driver of the heavy vehicle is, the more risk exists. That can be due to two main reasons, the first of them is the less experience of the driver, and the second the possibility of existing a larger figure of drivers in the ages where the more risk exist.

The situation changes considering the car drivers. The obtained results corroborates the
data obtained by other different traffic statistics; these ones considers the youthful as high risk population, by the inexperinece and other factors of psicology type. In those statistics the risk goes down when the age of the driver grow. In order to stick out this fact, the number of accidents with drivers whose ages are between 18 and 25 years is multiplied by a correction factor that could makes it comparable to the rest of the ages group that include two more years. Analyzing this grafic it is observed a fall reefy lineal in the accidents probability when we pass from an age group to another.

FRONTAL COLLISIONS
LIGHT VEHICLE DRIVER'S AGE (-)
(1655+1688+1696)

The analysis of the injures suffased by the car and industrial vehicle drivers in the case of frontal collision, in the most reliable indicator to establish the agresibity of this type of accidents to every of implicated vehicles. It is observed than this type of collision is a high risk accident for the car and its occupants, because the probability of drivers's dead is of 86%, and 1% only the probability of stay unhurt. For the heavy vehicle driver the figures are changed, 3% is the probability of die in the accidents by a collision of this type and 66% is the probability of stay unhurt. Moreover, in the most cases the death of the heavy vehicle driver or the gravity of his injures is produced by another collision after the frontal one with the car, due to the loss of control or because lefting the way.
These data stick out notably the aggressivity of the industrial vehicles to the rest of the vehicles which circulates in the road, or to ones that can be implicated in a traffic accident, as reflect the rate, obtained from the analysis of the available data:

- Nº of deaths/accident (1.41)
- Nº of deaths/accident from car (1.36)
- Nº of deaths/accident from heavy vehicle (0.05)
- Nº of serious wounded/accident (0.63)
- Nº of serious wounded/accident from car (0.46)
- Nº of serious wounded/accident from heavy vehicle (0.17)
- Nº of light wounded/accident (0.48)
- Nº of light wounded/accident from car (0.15)
- Nº of light wounded/accident from heavy vehicle (0.33)
- Nº of unhurt people/accident (0.67)
- Nº of unhurt people/accident from car (0.01)
- Nº of unhurt people/accident from heavy vehicle (0.66)

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**Fig. 4.a. Frontal collisions heavy vehicle driver's injuries.**
FRONTAL COLLISIONS
LIGHT VEHICLE DRIVER'S INJURIES

This agresivity for the car is also reflected in the probabilities of injury obtained by the car driver and its occupants depending on their position in the vehicle.

<table>
<thead>
<tr>
<th></th>
<th>Driver</th>
<th>Passenger on front seat</th>
<th>Passenger on back seat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead</td>
<td>86%</td>
<td>58%</td>
<td>32%</td>
</tr>
<tr>
<td>Serious</td>
<td>10%</td>
<td>34%</td>
<td>47%</td>
</tr>
<tr>
<td>Light</td>
<td>3%</td>
<td>8%</td>
<td>21%</td>
</tr>
<tr>
<td>Unhurt</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

This probabilities have served as a base to define a SEVERITY INDEX, which is used as a measure to compare the severity of different accidents from the case point. This index has been defined as:

\[
IS = M + G \times 0.517 + L \times 0.180 + (5 - (M + G + L + J)) \times 0.333
\]

\[
M = \text{number of dead occupants of the car in the accident.}
\]
G : number of serious wounded occupants of the car in the accident.
L : number of light wounded occupants of the car in the accident.
I : number of unhurt occupants of the car in the accident.
0,517 : standard average probability of being serious wounded in the accident.
0,180 : standard average probability of being light wounded in case of having travelled as an occupant in case of the accident.
0,333 : standard average probability of being wounded in case of having travelled as an occupant in case of the accident.

Occupant is every person who was travelling in the car in the moment of the accident, driver included. This index takes values between 0 and 1. The value zero is taken by those accidents where the five car occupants, who are considered to be the maximum that the car can transport, turn out unhurt. The value one is taken by those accidents where the five occupants of the vehicle turn out dead in the accident. To compare accidents where the number of occupants is variable, the last term of the severity index evaluates the injury probability of the people who could have occupied those places of the car where there was nobody at the accident moment.

This SEVERITY INDEX has been applied to the different accidents that are filed in the data bases, obtaining an average severity index for the different vehicle categories. Taking account that the sizes of the analyzed samples are very different, because the main part of the vehicles to which it has been applied the index can be considered included in the low range, a total of 476, 436 of the medium range and only 77 of the high range, the conclusions extracted of them can be significant.

<table>
<thead>
<tr>
<th>SIGN AND MODEL OF THE CAR</th>
<th>LOW RANGE</th>
<th>MEDIUM RANGE</th>
<th>HIGH RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(CODIFIED)</td>
<td>0.5157</td>
<td>0.5329</td>
<td>0.5373</td>
</tr>
<tr>
<td>(Typical deviation)</td>
<td>(0.0127)</td>
<td>(0.0229)</td>
<td>(0.0201)</td>
</tr>
</tbody>
</table>

Fig. 6. Severity index for cars depending category.

The average obtained results seems indicate a higher severity index whose the vehicle size grows up. This apparent contradiction can be explained if one of the fundamental variables in this type of accidents is considered: the circulation velocity in the moment of the impact. As it will be seen in the next paragraph, the velocity is highly connected statistically with the accident severity. By severity it is considered the injuries suffered by the occupants of the implicated vehicles. The higher velocity level that let the high range cars, giving to the driver more comfort and safe level, can explain the fact that they circulate faster and consequently the velocities of impact are higher too than smaller vehicles or vehicles from lower ranges, growing therefore, the risk of injuries for their occupants.

At least and relating the most frequent causes of this type of accidents, as it was already marked talking about the type of road where this types of accidents take place usually, the fundamental reason is the left invasion, produced during overtakings.

Another reason or cause of accident, although for away from the first one, is carrying
out non regulated handlings, and overtakings on prohibited areas.
The vehicles irruption in the roadway, the inadequated velocity or the driver's
distractions, may produce a left invasion, with the possibility of a frontal collision.
In a 79% of the cases the responsible of this type of accidents is the car driver, and in
a 20% the heavy vehicle driver, while in a 1% of the cases, the accident is caused by
both or by and external agent to both drivers, as it can be a non regulated handling
made by another vehicle, atmosferic conditions...

3. Results of the traffic accidents reconstruction

In order to achieved a detailed analysis of the features, causes and consequencies of
these accidents, the GIVET has developed a complete accident researching program in
situ, carried out in the province of Madrid cooperating with the D.G.T. and the
Agrupación de Tráfico de la Guardia Civil.
The deep analysis of the accident has as objectives: first, provide to the researching
equipment date enough about the circumstances in wich the accident occurred, to let its
complete reconstruction. Second and paralelly, reach to know the type of injuries
suffered by the passengers of the implicated vehicles in the collision (surpassing of the
fisiological tolerance limit of the human body to the accelerations, collapses,
ejections...).
First of all it has been applied the severity index to the sample of accidents studied in
situ. The average value obtained for this index is 0'5154 with a typical desviation of
0'1220.
In more than 90% of the studied accidents, the cause of the deaths or the wounds
suffered by the car occupants has been the collapse produced by the structure of their
own vehicle, and consequently, the survival space is seriously reduced after the impact
against the truck. Only 9'67% of the death cases were due to ejections of the occupants.
The severity index has been applied to the accidents in which the car compartiment
suffers an strong strain, having an average value of 0'5209, while in the cases where
the car compartiment stays practically the same, without considerable strains, the
average value of the severity index is 0,5032 (with typical deviatiuns similar to the
whole sample). The sudden decelerations experimented by the car during the impact,
and therefore its occupants, as we are seeing afterwards, make the differences in
relation to the accident severity not very big, with or without any strain of the car
compartment.
There is really differences about the severity depending on if the car penetrates into the
lower part of the industrial vehicle. In 73% of the studied accidents there was
penetration of the car into the lower part of the truck, obtaining an average severity
index of 0,5399, while in the cases where there wasn't penetration, this value gets down
until 0'4682, which is really lower the average severity index of the sample.
The variables considered as fundamental studying the severity of this type of accident,
has been first the geometry of the collision and second the masses and velocities of
these vehicles at the impact moment, therefore, the energy of the collision.
The impact angle has been defined as the angle between the longitudinal velocity vector
of the industrial vehicle and the longitudinal velocity vector of the car, considering as
positive angles the ones in the opposite direction to the clock hands. For the statistic study have been considered five clearances, having the following results:

<table>
<thead>
<tr>
<th>Impact angle</th>
<th>% Accidents</th>
<th>Severity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha = 180^\circ)</td>
<td>14.23%</td>
<td>0.5698</td>
</tr>
<tr>
<td>(180 &lt; \alpha &lt; 225)</td>
<td>51.43%</td>
<td>0.5048</td>
</tr>
<tr>
<td>(135 &lt; \alpha &lt; 180)</td>
<td>8.57%</td>
<td>0.5277</td>
</tr>
<tr>
<td>(135 &lt; \alpha &lt; 180)</td>
<td>22.86%</td>
<td>0.4900</td>
</tr>
<tr>
<td>(\alpha \leq 135)</td>
<td>2.86%</td>
<td>0.5998</td>
</tr>
</tbody>
</table>

Despite the amplitude of the chosen clearances, it is assured that the 80% of the sample is placed in angle values of \(180^\circ \pm 10^\circ\).

Apart from the case of \(\alpha \leq 135^\circ\) where there is only one accident, it is observed that the highest average severity index is obtained in the case of totally frontal collision. In 66% of the studied accidents the car strikes on the left third of the frontal part of the truck, in 25% of the cases it strikes on its central part and only in 9% of the cases on its right third, results that are coherent with the most probably causes of this type of accidents, which were already quoted. Applying the severity index to there three possible cases, the highest average value has been found in the case where the car hits the right third of the frontal of the truck, with 0.6797, second the central area with 0.5476 and third the left third with 0.4818.

Refered to the horizontal overlapping, considering as it the percentage of the car frontal with that contacts directly with the frontal of the truck, it takes an average value of 60.78% in the studied cases, existing an statistic correlation of 0.15 between this factor and the severity index.

The average energy appeared at the impact moment is of 3.73 MJoules, with maximum and minimum values of 10.43 MJoules and 0.21 MJoules respectively. Between this variable and the severity index exists a statistic correlation of 0.38. Among the independant variables that integrate that energy (masses of both vehicles and velocities of both), is the car velocity at the impact moment the one with a higher statistic correlation with the severity index.

Considering the most frequent accident in the spanish roads, rigid truck with medium range vehicle, it is defined, looking at this average energy level, what could be described as a typical accident, consisting on a truck with a mass around 17 Tm, circulating at 66 km/h at the impact moment and a car of 1080 kg, circulating at 94 km/h.

The energy percentage consumed in the vehicles strain is very variable, depending basically on the geometry of the impact and the structural features of the implicated vehicles in the collision. However, it has been concluded through the reconstruction of these accidents by computer than the total absorbed energy in the strain does not grow paralelly to the total energy appeared on the impact, instead of it, when the initial energy is increasing, this tends to a value that could be a limit one, nearby to 1.7 MJ.
Fig. 7. Horizontal overlapping vs. Severity Index.

Fig. 8. Energy vs. Severity Index.
As it was already said, in almost all the accidents, it is produce a severe invasion of the car survival space, basically in that area placed to a height where the direct impact is received, aggravated by the fact that causes by the height difference between the front of the car and the front of the truck, it is produced a penetration of the tourism in the lower part of the truck, receiving a direct impact the area of the windscreen frame and the doors frame and being completely destroyed as consequence of it.

On the other hand, the industrial vehicle usually receives medium damages which affect to the bumper, spotlights, and approximately in a 50% of the cases to the tyres, the front wheel rim and the steering, causing losses of control in the vehicle that can produce grave secondary accidents.

These strains cause a desigual distribution of the consumed energy in strain. The obtained data until the moment of the simulation indicates that the average relation between the strain absorbed energy by the industrial vehicle and the absorbed by the car, is approximated to values of 0.25.

At least, only point that the average deceleration values suffered by the vehicles at the impact, obtained by the simulation, similar to the ones suffered by its occupants, is around 6 g. for the industrial vehicles (depending highly on the category of the vehicle), and around 90 g. for the car.

Gratitudes

The authors wish to express their gratitude to the sign SUPERVISION Y CONTROL S.A. because of the financing of the project PROSYC, since the study introduced in this paper constitute a part of the mentioned project.

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THEORETIC MODEL FOR THE COMPUTER ANALYSIS OF VEHICLE COLLISIONS

Abstract

The complexity of the study and reconstruction of traffic accidents justifies the creation of tools which make easier the research in that area. That is the reason why the GIVET has developed a program called SINRAT III that lets, by means of dynamic simulation, reproduce the evolution of two vehicles in an accident in which a collision takes place, letting analyze the precollision and postcollision movements, as well as study what happens during the contact and deformation of the vehicles in the collision stage. The simulation model is integrated by bodies developed using the bond graph technique, that lets the simulation of the dynamic behaviour of the vehicles in any circumstance. At the end of this paper, an application example is presente, corresponding to an accident with collision between car and coach.

1. Introduction

This paper introduces the program SINRAT III and its concrete application in vehicle collisions reconstructing. SINRAT III is formed by two tridimensional models, correspondig to both vehicles. The movements of the vehicles before the collision are simulated, taking account of their velocities and the actions on the steering, drive and braking systems. The collision is simulated considering the local stiffness in the contact points of the vehicles and their deformations. Finally, postcollision movements are simulated until the vehicles stops completely.

The models are developed by using the Bond-Graph technique. In synthesis, the models consider the suspended mass as a rigid body with tridimensional movements, which joins the wheels through the suspension system. The suspension can be pneumatic, simulating in this case the variable stiffness of the air spring and the stabilizer bar in case of having them.

The steering, drive and transmission systems can also be simulated. When collision starts, models take into account the stiffness and necessary dampings to simulate the deformation in the car.

In the last part of the work, a practical case about the application of the SINRAT III is presented.

2. Modelling the vehicle

The SINRAT III contains two complete models of vehicles, that allow the simulation
of the dynamic behaviour of each vehicle before collision, during collision process, as well as the dynamic behaviour of both vehicles after collision.

In figure 1, a scheme of the model of the vehicle is shown, in which the main degrees of freedom are indicated.

![Fig. 1. Modelling of the vehicle.](image)

To define the mechanical model, bond graph technique has been used.

We consider five rigid bodies, corresponding to the chassis and the four wheels of the vehicle.

Body 1 represents the chassis. To define its movements, a right-handed reference system fixed at its center of mass is used, with the z-axis pointing vertically downwards, and the x-axis pointing forward in the moving direction of the vehicle.

Cardan angles which define the orientation of this system of reference are a turn $\gamma$ of the inertial base around the z-axis, followed by a turn $\beta$ around the y-axis of the new base, and finally a turn $\alpha$ around the x-axis of the last base.

Bodies 2, 3, 4 and 5 represent the vehicle four wheels. Their centers of mass are assumed so that they coincide with their centers of rotation. To define the wheels' movement, a coordinate system is used centered on the wheel center of mass, with its x-z axes situated in the plane of the wheel, and the y-axis perpendicular to that plane.

Due to the wheel point of contact with the ground varies constantly in a reference system fixed to the wheel, an auxiliary base will be used. This base will help to determine the wheel orientation, and will be defined such that the point of contact with the ground is fixed in this reference frame, with coordinates $(0,0,R)$, where $R$ is the radius of the wheel. The plane defined by the x and z axes of this last base will always be perpendicular to the plane in which the wheel spins.

Cardan angles which define the orientation of the bases which determine the wheels' movement are a turn $\gamma$ around the global z-axis of the body system, followed by a turn...
When the load process is stopping on the whole, the elastic element goes recuperating its initial amplitude, returning part of the absorbed energy (elastic recuperation). In the viscous damper the strain speed goes decreasing until it values cero at the end. Finally the displacement of the whole viscous damper/Coulomb, determines the permanent or residual, as well as the absorbed energy in the process. The recuperation of the elastic part of the model represents the energy fraction returned to the system, that in classic methods of analysis is evaluated using the restore coefficient of Newton. In order to establish the valves of the dampers and the spring for each type of vehicle, is necesary to board a deep study of the automobiles vehicles typical structure. That serves to characterize the behaviour of the different areas of the vehicle and allow the definition of a model of complet vehicle without considering the front, the lateral and the rear as parts with the same global behaviour.

The work hypothesis obtained from the automobile vehicles structural study that have subsequently served to configure the impactation of the basic impact element previously described, have been the following:

**Car front part**

Every vehicle with forward engine, independently of having a longitudinal engine or a transverse one is characterized by being more rigid at the height of the longitudinal rails, wich are placed at the frontal corner than in the central part.

When the engine dragger begins to produce after a collision, the rigidities of this parts are equalized, and as is going deeply, the whole rigidities, due to the dragger of the engine and another mechanical elements of the vehicle.

a) The frontal of the vehicle is much more rigid (about three and six times) at the bumper height than over it.

b) The rigidities or the strengh to the frontal strain, go increasing as is penetrating on it, due to the conical designs of the longitudinal rails (nor for all car model although observed in the last generation car, since its structure is conceived to resist impacts).
around the x axis of the new base, and finally a turn \( \beta \) around the y axis of the mobile base.

The wheels are attached to the chassis by means of springs and dampers in the three directions x, y, z which simulate the vehicle's suspension.

With regard to the simulation of the tyres behaviour in contact with the ground, the model of Bakker, Nyborg and Pacejka (1987) is used.

On the other hand, the action of motor torque, braking and steering must be transmitted to both the wheels and chassis through their respective angular speeds.

The models also include the transmission system and the gearbox, considering all its possible transmission relations, and the differential group. The engine is included in the models by means of the motor torque curve.

Using the bond graph technique in the development of the models, the different subsystems such as the mentioned in the above paragraph, are introduced in the global model without any difficulty.

SINRAT III uses the DASSL code as numerical integration algorithm for differential equations. The integration algorithm is based on the suggestion of solving a DAE system by substituting the derivatives of the variables for a difference approach and then solving the corresponding equations.

The program works as a unit to which access is possible from the computer operating system. The program has a preprocessor with which all the characteristic datum of the vehicles, the road and the actions of the drivers over the steering, brake or accelerator are introduced. This preprocessor is designed in a way that it is flexible and easy to use. It has also the possibility of correction of wrong inputs and modification of parameters for new hypothesis analysis.

Once the data input process is ended, the simulation module proceeds with the calculations following the mathematical models that represent the vehicles, and store the results in a file to be processed later through the postprocessor.

The postprocessor allows the graphical representation of the time evolution of the variables for the vehicles. It allows too the tridimensional representation of the trajectory followed by the vehicles, being able to see clearly the longitudinal, transversal and yaw movements during the simulation time.

3. Collision model between the two vehicles

The collision model developed consists, basically, in placing at the contact points between the two vehicles, damper-spring elements in serie in the longitudinal and transversal directions at each one of the two vehicles, that will allow to simulate the vehicles' body deforming behaviour during the collision, and the forces between vehicles in the contact point. (Fig. 2).

Each element is formed by an elastic linear element (K), a viscous damper (R) and a Coulomb damping, placed as the Figure 2 shows.

The elastic element K is linear and represents the behaviour in the elastic zone, simulating the range in which the strain varies linearly with the applied force. Inside this stage, if the actuating forces stop, the initial position is recuperated, and without
remaining permanent strain. In the consulted bibliography in relation with vehicle collision tests, the concept of minimum speed of permanent strain appears, defined as the test speed of a vehicle against a rigid barrier at zero degrees and with and overlapping of the 100%, to which it is not produced a permanent deformation in the vehicle. Through experimental tests of different models it has been established an average value of this speed, approximately 8 km/h (2,2 m/s).

From another point of view, considering this minimum speed of permanent strain, it is possible to calculate the value of the force from which it begins to produce permanent strains. To represent this phenomenon, a Coulomb damping (\( Y \)) has been introduced in the model. (Fig. 3).

This Coulomb damping is characterized for being infinite until a certain force level (null strain with the applied force) and once this force level is reached, the value of the force is constant and the strain growing constantly during the time that the force is applied.

The strain speed and the reached permanent strain, are determined on each element by the features of the viscous damper (\( R \)). In this case the value of the viscous damper has been made variable with the strain, in a way that the linear relation between strain speed and force is not constant.

Like the elastic element and the whole of the viscous damper/Coulomb damping are in serie, both are submitted at every moment to the same load. While the load takes lower values to the one of the Coulomb damping, only the strain is produced in the elastic element (elastic strain).

Once the load reaches the values of the Coulomb damping in the whole viscous damper/Coulomb, the actuates forces are distributed between both elements, in such way that in the Coulomb remains constant the force for which it has been adjusted and the viscous damper is the one that absorbs the rest of the force determining the strain speed of the whole as a function of its characteristics.
c) The reaction forces of the longitudinal rails of the frontal must transmit to a very rigid parts of the rest structure. Generally, the passenger compartment is rigid enough, specially:
- Propeller shaft housing.
- Vehicle floor.
- Windscreen pillars and rear windows.

Car lateral part
a) The rear part of the lateral, exceed the rear door, the lateral area of the vehicle floor and the lateral area of the front between the suspension anchorage and the forward door, are the most rigid of the car,

b) The lateral area included from the former extreme of the car until the height where are placed the suspension anchorages, is less rigid enough,
c) The area occupied by the doors of the car is the least rigid of the whole lateral.

Car rear part
a) One of the reasons why the rear part of a vehicle is usually the most rigid part of it, is because it must be avoid the breaking of the fuel tank when is placed in this part. For vehicles of the same size (same category), there aren't big differences from the rigities point or view, for vehicles with or without rear door.

b) There aren't any data available to suppose more rigidity between any parts of the rear area.

From this remarks it is decided to adopt the following rigidities distribution:
1. Front part:
   - Group of six basic impact elements working in paralleled.
   - Vehicle doors area - 20%
   - Rear part - in this part it is decided to establish only one basic impact element that represents in a global way its structural behaviour.

Once it is established the distribution of the vehicle by areas, is necessary to determine the global values of the dampers and rigidities for the front, lateral and rear parts of the vehicle.

This values have been obtained using the data bases of the EDCRASH model and contrasting the model behaviour with real tests. [2].

About the Coulomb damping it has a damping coefficient of infinite value until the effort between both extremes reaches the effort between 2000 and 4000 N, depending on the mass and the size of the vehicle. When this effort is reached, the damping coefficient becomes zero.

The variable viscous damper is adjusted by a function of this type:

$$ R = 1.2R_0 = \frac{R_0}{2} C_T^2 $$

(1)

Considering:

$R_0$ - Value of damping parameter adjusted to each vehicle category.

With the following rigidities distribution compared with the total rigidity:
- Lower area of the front part C at the height of the longitudinal rails-bumper) - 75%.

The distribution is the following:
* Right corner (right longitudinal rail). - 30%
* Left corner (left longitudinal rail). - 30%
* Central area. - 15%

Fig. 4.

2. - Lateral:

Group of three basic impact elements working in parallel to differentiate between three areas of different rigidity. This areas and the rigidities distribution of them compared with the total distribution are the following.
- Rear area of the lateral, not including the rear door, lateral area which is placed at the height of the vehicle floor and lateral area of the front part between the suspension anchorage and the forward door - 55%
- Area of the lateral located between the former extreme of the vehicle until the height where are placed the suspension anchorages - 25%

Fig. 5.

CT - Total deformation at every instant.

The global values of the rigidity of R₀, are shown to each area in the table n°1.
Table 1

<table>
<thead>
<tr>
<th>CATEGORIA</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R_0$ (N·s/m)</td>
<td>$R_0$ (N·s/m)</td>
<td>$K$ (N/m)</td>
<td>$K$ (N/m)</td>
<td>$K$ (N/m)</td>
</tr>
<tr>
<td>FRONTAL</td>
<td>31224.65</td>
<td>36417.30</td>
<td>45798.70</td>
<td>49263.50</td>
<td>52372.69</td>
</tr>
<tr>
<td>REAR</td>
<td>2872521.6</td>
<td>3339526.6</td>
<td>4199816.4</td>
<td>4517543.6</td>
<td>4802652.0</td>
</tr>
<tr>
<td>LATERAL</td>
<td>32233.33</td>
<td>41318.03</td>
<td>47560.37</td>
<td>50354.39</td>
<td>58693.71</td>
</tr>
</tbody>
</table>

For each integration step, the model verifies if exists or not any contact between the vehicles by means of a routine that checks the existence of an intersection of the horizontal projections of both vehicles represented by two rectangles with their length and width dimensions. If a corner of any of the vehicles is introduced in the rectangle corresponding to the other, the model detects a contact between both. When it happens, the point is considered of contact between both vehicles. This process is made with all the corners of both vehicles, calculating in each integration step the new positions and the displacement of the contact points between them.

Afterwards, a pair of spring-damper elements, in longitudinal and transversal direction, that simulate the strains suffered, and the energy absorbed by the vehicle bodies, are associated by the model to each vehicle contact point. At the contact time, both stiffness and damping values are associated to the corresponding parts of the vehicles where the impact is verified. After that, the model calculates the strengths that are exerted between the vehicles, and the strains produced in the bodies as well. Once they are known, the new relative positions of the two vehicles are evaluated, as well as the new contact points. Then, the cycle is repeated successively, calculating new points of contact at other vehicles’ zones in order to introduce a new pair of spring-dampers at the new point of contact, if necessary.

When the maximum strain is reached in one of the contact points, and both vehicles begin to repel themselves, the springs-dampers are disconnected at the point. Once all the contact points shown in the two vehicles have been disconnected, the model of impact only analyzes the appearance of new contact points between the vehicles at their subsequent trajectories.

The collision model has also been developed by means of the bond graph technique, chaining two three-dimensional models of vehicles with models that simulate the behavior of the bodies during collisions, and the strengths that appear among them as well. The present model reproduces with accuracy the behavior of the bodies about the strains and energy absorptions.
4. Application of SINRAT III To the reconstruction of collisions between vehicles.

Figure 6 shows the stage of one collision between a Ford Fiesta car and a coach; at the moment of the event it was raining heavily, and that made the road be full of water, that seems to be the reason why the driver loses the control of his vehicle, following the trajectory indicated in the Fig. 6, overruns the opposite roadway and colliding with a coach.

In this case, SINRAT III has been used to reconstruct the accident. To do it, initially the characteristics of each vehicle are known, as well as their possible trajectories, point of impact and final situation of the vehicles.

With regard to these data and by means of SINRAT III, the accident is simulated varying the speeds of both vehicles, the adherence coefficients between tyres and road as well as introducing different braking manoeuvres made by the car driver.

![Fig. 6. Collision trajectories.](image)

Different cases of simulation that are created by variations indicated in the above paragraph, are solved, until the results coincide in trajectories, points of impact and final positions for both vehicles. In that moment, the simulation is finished and, with regard to it, the variation with the time of all the variables brought into play during the collision may be found.

In Figures 7 and 8 the reconstruction of the accident obtained by means of SINRAT III is shown. With regard to the results obtained from this simulation, the Ford Fiesta was running at a speed of 90 km/h, when the car driver lost the control of the vehicle. In these circumstances, the vehicle tends to leave by the right verge in the movement direction. Is then when the driver recovers the control, treating to straighten the car and, at the same time, works the brakes. In order the geometry of collision to coincide with the real, it has been necessary to employ an adherence coefficient of 0.3 and, a coach a speed of 80 km/h. Considering these values was possible to get the same simulated damages on both vehicles that in the real accident.
In figure 9, the deceleration of both vehicles are shown as function of the time. It is observed that during the collision there is a strong deceleration increment, much more for the car than for the coach, because of the mass differences between both vehicles. In this case 664 m/seg² is the car deceleration and 39 m/seg² is the coach one. Figure 10, shows the strain energy absorbed by each vehicle, and it is observed that this is much larger in the car than in the coach. The knowledge of this energies distribution is basic in order to redesign or incorporate new structures to the front of the coaches, since it gives an idea of the energy absorption which is necessary to have in the coaches,
Fig. 9. Accelerations (m/seg²) during the collision.

Fig. 10. Absorbed energies (Joules) during collision.
in order to reduce the consequences that this type of collisions have for the car occupants.

5. Conclusions

In this paper, it has been presented the program SINRAT III, developed for the computer simulation of the behaviour of vehicles in collisions. The model used allows to analyze deeply the vehicle dynamics during the precollision, collision and post-collision processes. Because of the use of the Bond-Graph technique the developed models allow the inclusion of any new subsystem or mechanical elements. By means of the simulation with SINRAT III, traffic accidents may be reconstructing, making possible reaching to determine with enough approximation, the speed of vehicles before the collision, manoeuvring of steering or braking made by the drivers, and decelerations, strains produced and distribution of absorbed energies by the bodies of the vehicles.

References
FULL SCALE COLLISION TESTS

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Abstract

The Association for Structural Improvement of Shipbuilding Industry (ASIS) and the Netherlands Foundation for the Coordination of Maritime Research (CMO) jointly conducted a series of collision tests on full-scale ships in December 1991.

Four different tests were carried out using two fully instrumented tankers for inland waterway navigation.

The results of the test will be used to verify calculation methods for the prediction of damage to ship structures from collisions or from groundings.

In order to be able to make a proper judgement of possible ship structures and thus enable improvement of safety levels of marine operations, it is important that such methods are available. Although prediction methods are available, no full scale experiments have been carried out before, for verification.

In the project the four full-scale collisions have been simulated afterwards using the MSC/DYNA program, a non-linear finite element program, which enables the full simulation of the dynamics of the impact event.

The results of this simulation compare quite well to actual measurements.

1. Introduction

Although accidents with ships have a history which reaches as far back as shipping itself, there are a number of accidents which have attracted a lot of attention. From the beginning of this century the "Titanic" disaster is well known. In recent years the accidents with the "Herald of Free Enterprise" and the "Exxon Valdez" have
made the headlines. All these accidents have had their impact on the regulations.
The public pressure after the grounding of the "Exxon Valdez" in the Prince William Sound resulted in the Oil Pollution Act of 1990 (OPA 1990) which passed U.S. Congress in August of that year.

With regard to design of the vessel, the most important part of this law is the regulation that all tankers whose contract is placed after June 30, 1990, may not operate in US waters unless equipped with a double hull.

Existing single hull vessels are allowed to sail until they reach the age of 25 years, but only until the year 2010.

The Oil Pollution Act is criticized because a fixed design standard is employed rather than a performance standard in which only the maximum probability of a certain outflow of cargo would be given.

With regard to inland waterway navigation in North West Europe, the traffic density is very high. At a number of places there is a large number of people living on the banks or near the transport waterways.

An accident in which there is outflow of hazardous material might therefore end in a disaster.

In the Netherlands the question was raised about the level of safety and the possibilities for a further improvement of the safety level. To provide an answer to this question, in 1988 the project "Veiligheid Vervoer over Water" (Safety of Inland Waterway Transport) was started.

One of the items covered in this project is the calculation of the probability of loss of containment, given a hypothetical accident with a hazardous cargo ship [1]. A number of simulations were carried out in which the mechanical damage caused by a collision is calculated.

In fact, there are several calculation methods available, to determine crush worthiness of ships. However, no full scale experimental data were available which could be used to verify these methods.

In order to generate full scale data, a series of four collision experiments was carried out with two inland waterway tankers of approximately 1000 tonnes displacement.

The experiments were carried out by the Centre for Mechanical Engineering of the Netherlands Organisation for Applied Scientific Research (CMC-TNO). Computer simulations of these experiments were executed by the MacNeal Schwendler Company. The Netherlands Foundation for the Coordination of Maritime Research (CMO) acted as principal. The project was sponsored by the Japanese Association for the Structural Improvement of the Shipbuilding Industry (ASIS), represen-
ted by Mitsubishi Heavy Industries (MHI). Other sponsors were the Netherlands Ministry of Transport and Public Works and the Netherlands Central Bureau for Navigation on the Rhine and Inland Waterways (CBRB). The results are reported in [2] and [3].

2. Description of tests

The tests were carried out in a harbour basin near the village of Moerdijk in the Netherlands. This basin has a length of 1900 meters, a width of 150 meters and a depth of 9 meters.

The striking ship could first take up speed on the river outside the harbour and then turn into the harbour at the required striking speed. The stretch in the basin was used for aiming at the striking location and for some final speed adjustments. After the collision the striking ship started withdrawing immediately by giving full astern. At each collision the bow of the striking ship hit the side of the struck ship at a right angle (90 degrees).

The general particulars of the striking ship and the struck ship are shown in Table 1.

The bow of the striking ship was reinforced by a double plating of 15 mm. welded all around. Also additional stringers were fitted. Moreover, the lower part of the forepeak was filled with concrete. Therefore no plastic deformation occurred due to the collision forces. The anchors at the bow of the striking ship were removed prior to the collision tests.

<table>
<thead>
<tr>
<th></th>
<th>Striking Ship</th>
<th>Struck Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>RANCO</td>
<td>BORIS</td>
</tr>
<tr>
<td>Length over all</td>
<td>79.92 m.</td>
<td>80.05 m.</td>
</tr>
<tr>
<td>Beam</td>
<td>8.20 m.</td>
<td>8.21 m.</td>
</tr>
<tr>
<td>Depth</td>
<td>2.80</td>
<td>2.80</td>
</tr>
<tr>
<td>Draught min.</td>
<td>0.64 m.</td>
<td>0.71 m.</td>
</tr>
<tr>
<td>Draught max.</td>
<td>2.48 m.</td>
<td>2.62 m.</td>
</tr>
<tr>
<td>Displacement min.</td>
<td>351 tonnes</td>
<td>389 tonnes</td>
</tr>
<tr>
<td>Displacement max.</td>
<td>1447 tonnes</td>
<td>1529 tonnes</td>
</tr>
</tbody>
</table>

Table 1: General Particulars of the striking ship and struck ship
The struck ship "Boris" was built as a single hull dry cargo ship and at a later date converted into a tanker. At that occasion, the longitudinal bulkhead, the upper part of the trunk and the trunk deck were added. Especially for the tests two of the cargo tanks were modified to change the single side structure into a double side structure. The extra longitudinal bulkheads were fitted along the length of tank 2 on port side and tank 3 on starboard. (Figure 1)

In tank 3 the original outer shell and the newly built inner shell were connected to each other by a stringerdeck. Figure 2 and 3 show the structural arrangement of a single side and a double side structure.

3. Measured data

During the collision the following parameters were measured.
- The penetration of the bow of the striking ship into the side of the struck ship;
- The contact force between the striking ship and the struck ship;
- The strains along the connection of the maindeck with the trunk in case of a single shell and along the connection of either a stringer or a stringerdeck with the inner shell in case of a double shell.
- The rigid body motions of both the striking and the struck ship.

The penetration of the bow of the striking ship into the side of the struck ship was for reasons of redundancy, measured by means of three different devices. The first device consisted of two wire gauges, measuring displacement velocity as a function of time. The wire gauges were mounted on the trunk deck of the struck ship. The end of each wire was fitted with magnets to lock them to two catching plates which were fitted to the striking ship just before the actual instant of impact. The second device consisted of two ultra sonic displacement gauges, mounted on the striking ship. These devices pointed forward towards echo plates at the side of the struck ship. Thus an echo could be received from which the displacement as a function of time could be determined. The third device consisted of a high speed camera mounted on the bow of the striking ship at 6 meters above the deck. This camera, and two others installed inside the tanks to be collided, was time calibrated and therefore could be
used to determine approach velocities and relative deceleration of the striking ship with reference to the struck ship.

The contact force between the ships was measured directly by a series of specially made load transducers, 21 in total, fitted between the reinforced bow of the striking ship and the main hull (Figure 4). Two of these load cells were fitted in a vertical direction to measure the vertical load on the bow during the collision. The other 19 load cells were fitted in the direction of the centerline of the ship. The measured contact forces were the forces acting between the bow of the striking ship and the hull aft of frame 137. The actual collision force between RANCO and BORIS will be approximately 4.5% higher because of the inertia force of the bow.

The mass of the bow was estimated at 45 tonnes out of 1000 tonnes of the whole ship.

The rigid body motions of the ships were measured by eight accelerometers per ship. Figure 5 shows the locations of the meters of the struck ship. Near both ends of each ship, a set of three accelerometers was fitted each of which measured in either longitudinal, transverse and vertical direction. About midships two additional accelerometers were mounted in the port and starboard side measuring in a vertical direction. The accuracy in which the accelerometers were directed was plus and minus 0.1 of a degree.

All measuring equipment on both ships was triggered at the same time by the breaking of two neon-light devices (both ships one device) caused by colliding. At the time of triggering the distance between both ships was approximately 0.5 meters.

4. Numerical simulations

Each of the four collisions was simulated by MSC using the same methodology which had been used since 1989 for the simulation of collisions of inland waterway tankers which were performed for the Dutch Ministry of Transport and Public Works.

The numerical methodology consists of three separate computations.

In the first step the collision of both ships is simulated in free space without the influence of water. The vertical motion of the ships is constrained to zero, thus both ships can only move in a horizontal plane. The collision process
is completed by employing the three-dimensional explicit transient dynamic finite element program MSC/DYNA. For reasons of computer time reduction only a small part of the struck ship in the collision region (half of the ship's width and over a length of 18 m.) was modeled in detail with shell and beam element as a deformable structure (Figure 6). The remaining part of the ship has been modeled as an undeformable rigid body. The whole of the striking ship has been modeled as a rigid body too. The result of the first step is a first estimate of the time dependant collision force.

In step 2 the water reaction force will be determined. The influence of the water will appear as a resistance force acting in lateral direction on the struck ship. To determine this resistance force a numerical simulation was made in which the time dependent collision force calculated in step 1 was applied to a rigid model of the struck ship floating in the water. This calculation will use a two dimensional transient symmetric model of the water and a cross section of the ship of 1 meter length. From this calculation with the MSC/PISCES code the resistance force per unit length is determined as a function of velocity. A two dimensional calculation can be used because in the simulations almost no rotation of the ship around the vertical axis occurs and the ship will only have a translational motion in the transverse direction and a rotation around its longitudinal axis.

The third step is a repetition of the first step calculation, now with a more complete model using the results of the phase 2 calculation. The resistance force of the water is modeled by a series of 26 dampers attached to the non collision side of the struck ship. The characteristics of these dampers are computed from the results of the step 2 computation. There the resistance force per unit length was found and by multiplying it with the length of the ship the total resistance force on the ship is known. By doing this, the dampers take the acceleration of the water around the ship into account. In the numerical model in phase 3 this total resistance force is evenly distributed over the 26 dampers. This approach results in one characteristic for all dampers. To take into account the vertical motion of the struck ship a system of 26 springs is supposed attached to the bottom of the ship. These springs represent the static hydro-
dynamic water forces and allow the struck ship to have a vertical displacement and also to rotate along its longitudinal axis.

5. Results

In Table 2 some results of the collision tests and the numerical simulations are given.

<table>
<thead>
<tr>
<th>Test</th>
<th>Initial speed of striking ship (m/s)</th>
<th>Penetration (m)</th>
<th>Maximum contact force (MN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>collision</td>
<td>simulation</td>
</tr>
<tr>
<td>1</td>
<td>1.5</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>4.1</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>4.2</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>4.3</td>
<td>0.9</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 2: Results of actual collisions and numerical simulations.

From this table it can be seen that the simulations were successful in computing one of the main features of the collision process; the penetration depth. For all four tests the deformation pattern in the simulation was in good agreement with the test.

In each collision initial cracking of the shell occurred at a weld.

In the simulations the holes were found at the strike locations. In test 3 the crack in the actual collision and the simulation were about 1 m. apart from each other.

A better match could have been obtained when at that spot the weldline would have been modeled by a number of numerical elements with a material model with a substantially reduced maximum plastic strain.

The maximum computed collision forces are 30-70% higher than the measured maximum collision forces. As mentioned
before the difference between the actual collision force and the measured collision force is approximately 4-5%. The fact that in the numerical simulation both ships are modelled as rigid bodies will also contribute to the difference between the measured and computed maximum forces.

6. Conclusions

- The collision tests carried out have been successful and yield valuable information with regard to ship’s collision damage resistance. This refers especially to the behaviour of the side/deck structure when subjected to a collision with a ship’s bow.

- Numerical simulations can be used to predict penetration depth, shape of collision area and hull size given a hypothetical collision between two ships.
References:


15 februari 1993
• Striking ship "Ranco"

• Struck ship "Boris"

Figure 1: General arrangement of colliding ships
Figure 2  Single side structure
Figure 3  Double side structure
Figure 4  Arrangement of force transducers
Figure 5  Location of accelerometers
Figure 6  Numerical model
Abstract - The study concerns with the identification of the safety level in two main conurbation's in Cyprus. In particular the study consists of two phases and in this paper only the work included in the first phase is being described. The accident records for the period 1986-1990 from the cities of Nicosia and Limassol were studied after being transferred into well constructed data-bases. Both injuries and material damages were examined. In this first phase of the study a statistical analysis was performed separately for road intersections and road sections between intersections. Emphasis was given in the extraction of useful results that concern the distribution of the absolute accident numbers and the injuries against the hour, the day, the year, age etc. Also the main causes and the accident types were identified. Black spots identified for both urban areas.

It became clear that road safety in Cyprus needs to be studied carefully before any measures is to be taken that could reduce the accident risk in Cyprian urban areas.

Introduction

It is well known that road traffic accidents consist a significant problem in modern societies with many consequences in either personal or national scale. Those could be distinguished in:
1) Human casualties (fatal, serious, slight)
2) Material damages
3) Social distress
4) Economic consequences

Each year a significant number of people fall victims of road accidents and this seems to increase with the ever increasing rate in vehicle ownership. From the table with the road accident frequencies all over the world it is obvious that Cyprus possesses a dominant place having 20.93 fatalities per 100,000 residents (1989) and at the same time the level of car ownership is very high:
- 280 private vehicles per 1000 residents, and
- 1.95 residents per vehicles (1989).

Table 1 shows the distribution of the number of road traffic accidents, the number of injured persons and the accidents weight during the period 1986-1990.
Table 1: Annual distribution of accidents, injured persons, accidents weights for all Cyprus.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ACCIDENTS:</th>
<th>INJURED PERSONS</th>
<th>ACC. WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inj.pers.</td>
<td>%</td>
<td>max. &amp; min.</td>
</tr>
<tr>
<td>1986</td>
<td>3156</td>
<td>19.54</td>
<td>6679</td>
</tr>
<tr>
<td>1989</td>
<td>3342</td>
<td>20.69</td>
<td>7979</td>
</tr>
<tr>
<td>1990</td>
<td>3172</td>
<td>19.64</td>
<td>7936</td>
</tr>
<tr>
<td>Sum</td>
<td>16154</td>
<td>100</td>
<td>31857</td>
</tr>
</tbody>
</table>

Because of all those tragic consequences of the accidents lots of in-depth studies have been carried out during recent years trying to produce a better understanding of all the various components which contribute to those accidents. It is believed that the results of those studies will establish the basis for a more efficient traffic management policy towards road safety. In Cyprus a great deal of effort has been made towards this direction during the period 1989-1990 in close co-operation with Australian experts, the Police and the department of public Works. The studies that have been carried out during this period covered the whole Cyprus road network, urban and inter-urban, and comprised:

a) The creation of a road accidents management system.
b) The analysis of road accidents, and
c) Proposals for remedial measures at accidents black-spots in accordance with more comprehensive inferences in the city level as we.

The implementation of those proposals has already began since 1991 in a piecemeal basis simultaneously in urban and inter-urban areas of the road network.

At this point it is necessary to underline the Police effort to resposibilite people, change their altitude towards road safety and improve road driving conditions. To achieve this, Police increased the patrols, used every media form and organised public lectures in order to focus public's attention, especially drivers and pedestrians, on road safety.

Keeping in mind the situation described above, the Department of Transportation and Hydraulics of the school of Rural and Surveying Engineering at the Aristotelian University of Thessaloniki organised this research project with title "Road safety in urban areas in Cyprus."

The study areas are the Greater urban areas of Nicosia (Part of the Capital city is occupied by Turkish troops since the Turkish invasion of 1974 in the island) and Limassol, and the accidents that occurred at road sections or junctions during 1986-1990 were studied. However, due to more detailed information available, the research was focused on accidents that took place at junctions during the 5 years because the exact position of the accidents at the road sections was not reported.

The aims of this study were:

a) The identification of the black-spots (junctions with high accident frequencies) and
b) An in-depth understanding of the causes and the prevailing road conditions which contribute to the accidents in order to make specific proposals for the improvement of road safety at junctions.

We must underline that this is the first phase of the study which will be completed in the end of 1992.
Data collection

In order to fulfill the aims of this research the evaluation of the information concerning the road accidents that took place at the study area was necessary. These information are recorded on site by the police, afterwards they are being transferred to a specially designed statistical form which is used for the recording of the information in the data bank existing in the computers of the Department of Public Works. It must be noted that a new type of statistical form was proposed from the experts and its use has commenced since the beginning of 1992.

The information collected for this research were recorded in 3 separate data bases:

a) The first are contains information's describing the accident as an incident and includes 55 fields.

b) Information referring to the persons/vehicles involved in the accident are recorded in the second data base which includes 31 fields.

c) The third contains locational information about the accident and includes 7 fields.

The data bank contains another 2 data bases, one of them provides detailed information concerning accidents occurring at junctions and the other one is about accidents taking place at road sections. The first data base includes 16 fields and the second includes 80 fields.

The structure of those data bases is relied on the new statistical forms. This resulted in lots of unknown information because many of them were extracted from the old forms.

The data used for this research is:

- Date and time of accident.
- Exact location (this information was unavailable for the road sections).
- Number and type of the vehicles involved.
- Number and type (fatal, serious, slight) of the injured persons.
- Causes of the accidents according to Police judgement.
- Prevailing road conditions.
- Sex, age of all the persons involved.

The insufficiency of the old type registration forms lead in the absence of crucial information such as, the type of the collision, the exact spot of the accident at road sections and the manoeuvres of the involved vehicles before the accident.

These information are essential for the extraction of in-depth conclusions which will lead in proposals for the improvement of the geometric and operational features of the accidents black-spots. In addition to the above, traffic and geometric data was collected from the Department of Public Works.

This data set consists of:

1) Traffic flows for a number of junctions.
2) For the junctions with more than 25 accidents during the past 5 years a) detailed maps (scale 1:200 or 1:500) for the signalised intersections and roundabouts and b) sketches for the rest.
These maps and sketches contain: The position of traffic signals, traffic lanes, vehicles movements, traffic signs, middle islands, pedestrian crossings.

Information concerning any remedial measures on the geometric or operational features of the junctions which took place during 1986-1990 were also recorded.

Data Analysis

The method used for the analysis of the collected data is outlined in the following paragraphs:

a) Using the d-BASE-III PLUS software package, the data bases were separated in smaller parts, according to the year the accident took place, whether it occurred at an intersection or another road section, for the easier and better analysis of the data.
b) Specifically written programmes in d-BASE-III PLUS produced results which were tabulated in order to give us a better insight of the actual situation. Those results were later analysed in-depth in order to lead us in the final conclusions.

c) The creation and the calculations on the tables were made using the software package EXCEL 4.0 for windows.

Where it was thought most appropriate the presentation of the results was made in graphical form. (histograms-pies).

It has been already mentioned that this research focuses on the accidents occurring at intersections. They have been categorised in those involving a) human casualties and b) material damages only.

The statistical analysis follows the scientifically international accepted standards and is described as follows:
1) Distribution of the accidents per year, month, day, hour-(day/night)
2) Distribution by age.
   a) of the drivers involved in the accidents.
   b) of the human casualties -(fatal/serious/ slight)
3) Distribution by type of the injured persons involved (pedestrians, cyclists, etc.).
4) Distribution of the accidents in relation with the prevailing pavement (dry/wet/snow or ice/else).
5) Distribution by cause of the accidents - grouping of causes.
6) Distribution by vehicle type - grouping of vehicles types.
7) Comparative tables for the accidents occurring at intersections and other road sections for the years 1989-1990. (The construction of such tables was not possible for the other years due to missing information.)

Those tables revealed the need for a more detailed analysis of the: a) most important accident causes and b) the intersections where more than 25 accidents occurred. (The number 25 is based on the method of absolute number for the estimation of the dangerous intersections.)

The number of road accidents that took place in Nicosia during the study period was 19,705, 50.38% of them occurred at intersections, 14.43% at road sections and 35.19% at "unknown position" meaning that there was not any information about their exact spot.

No accidents were recorded for the years 1986-1988 for the road sections in both cities, and this is due possibly to the Police which did not record the exact spot of the accidents. Most likely they are recorded as "unknown position".

The number of accidents is relatively stable and the slight variation may be regarded as representative of the random manner of the road accidents.

In Limassol 12,197 accidents were counted, 56.93% took place at junctions, 16.96% at road sections and 26.11% at "unknown position". In contrast with what happens in Nicosia the number of accidents at Limassol shows a slight continuous increase during the whole study period.

Table 2: Annual distribution of accidents, injured persons, accidents weights in Nicosia.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ACCIDENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inj. per.</td>
</tr>
<tr>
<td>1986</td>
<td>452</td>
</tr>
<tr>
<td>1989</td>
<td>664</td>
</tr>
<tr>
<td>1990</td>
<td>646</td>
</tr>
<tr>
<td>sum</td>
<td>2648</td>
</tr>
</tbody>
</table>
Table 2 presents the annual distribution of accidents - injuries each year. In order to access the impact of each road accident according to its consequences a weighting factor is subscribed.

Those weighting factors are assigned as follows: Fatal injury = 45, Serious injury = 5, and Slight injury = 1. The weight of accidents is estimated as the sum of the multiplication's between the number of injuries and weighting factors for the above categories and the average accidents weight is the result of the division of the total accidents weight with the total number of accidents involving injuries.

Road accidents at Nicosia show a continuous slight increase during 1986-1988. There is a sudden 10% increase in the year 1989 and they remain at the same levels with the previous year in 1990 (table 2). In Limassol (table 3) the accidents increase rate follows approximately the same level as in Nicosia showing a sudden 12.5% increase in 1989.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ACCIDENTS:</th>
<th>INJURED PERSONS</th>
<th>AC. WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inj. per.</td>
<td>%</td>
<td>fatal</td>
</tr>
<tr>
<td>1986</td>
<td>371</td>
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<td>519</td>
</tr>
<tr>
<td>1987</td>
<td>369</td>
<td>17.08</td>
<td>539</td>
</tr>
<tr>
<td>1988</td>
<td>362</td>
<td>16.75</td>
<td>728</td>
</tr>
<tr>
<td>1989</td>
<td>510</td>
<td>24.53</td>
<td>1438</td>
</tr>
<tr>
<td>1990</td>
<td>529</td>
<td>24.68</td>
<td>1559</td>
</tr>
<tr>
<td>sum</td>
<td>2161</td>
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<td>4783</td>
</tr>
</tbody>
</table>

After the previous general but useful finding the main analysis of this research was focused on the road accidents with injuries which constitute the most "serious" category of accidents. From table 2 it can also be seen that in Nicosia the number of accidents with injuries is 2,648, 26.67% of the total and the injured persons involved are 29 fatally, 658 seriously and 2,795 slightly injured. The number of those accidents lies at the same levels for the first three years (86-88), there is a sudden increase of 8.5% during 1989 and in 1990 remain at the same levels as in 1989. The number of injuries lies approximately at the same levels except in 1987 where there was an increase of 16.45%. In Limassol (table 3), the number of accident involving injuries is 2,161, 31.12% of the total, and there are 18 fatal, 308 serious and 1,630 slight injuries.

The rate of variation is the same as in Nicosia with an increase of 7.8% in 1989 while the number of injuries shows minor oscillations.

Comparing tables 2 & 3 it can easily be seen that serious accidents occur more frequently in Nicosia than in Limassol with the correspondent accident weights lying between 2.21-4.9 and 1.7-2.13 in these two cities.

The accidents daily distribution (in both cities) shows that the number of accidents lies at the same levels during a typical working day and Saturday while in Sunday there are 6% fewer (of the total) accidents. More specifically the absolute number of accidents in Saturday is slightly higher from the average number of a typical working day in Limassol while in Nicosia is slightly smaller. This phenomenon is probably due to the increase traffic to the shopping centres during Saturday.

The accidents hourly distribution for Nicosia shows that 7.17% of the total accidents occur between 7-8h (morning peak) and 7.67% during 17-18h (evening peak) while in Limassol there are 4.85% during 7-8h (morning peak), 8.93% during 16-17h (evening peak) and 8.28% during 17-18h (evening peak). It is obvious that in Limassol there is a serious problem during the evening peak. The grouping of the hourly distribution proved the period between 7-14h as
Table 4: Distribution of accidents with injured persons per drivers ages in Nicosia

<table>
<thead>
<tr>
<th>YEAR</th>
<th>6-14</th>
<th>15-24</th>
<th>25-44</th>
<th>45-65</th>
<th>&gt;65</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>28</td>
<td>28.57</td>
<td>26</td>
<td>33.77</td>
<td>234</td>
</tr>
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<td>1988</td>
<td>17</td>
<td>17.35</td>
<td>13</td>
<td>16.88</td>
<td>123</td>
</tr>
<tr>
<td>1989</td>
<td>23</td>
<td>23.47</td>
<td>11</td>
<td>14.29</td>
<td>150</td>
</tr>
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<td>1990</td>
<td>16</td>
<td>16.33</td>
<td>21</td>
<td>27.27</td>
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</tr>
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<td>SUM</td>
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<td>100</td>
<td>77</td>
<td>100</td>
<td>747</td>
</tr>
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</table>

Table 5: Distribution of accidents with injured persons per drivers ages in Limassol

<table>
<thead>
<tr>
<th>YEAR</th>
<th>6-14</th>
<th>15-24</th>
<th>25-44</th>
<th>45-65</th>
<th>&gt;65</th>
</tr>
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</tr>
<tr>
<td>1989</td>
<td>14</td>
<td>21.88</td>
<td>6</td>
<td>21.43</td>
<td>105</td>
</tr>
<tr>
<td>1990</td>
<td>16</td>
<td>25.00</td>
<td>4</td>
<td>14.29</td>
<td>109</td>
</tr>
<tr>
<td>SUM</td>
<td>64</td>
<td>100</td>
<td>28</td>
<td>100</td>
<td>517</td>
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Table 6: Distribution of injured persons per ages in Nicosia

### Distribution of fatal injuries per groups of ages per year

<table>
<thead>
<tr>
<th>YEAR</th>
<th>[0-5]</th>
<th>%</th>
<th>(6-14)</th>
<th>%</th>
<th>(15-24)</th>
<th>%</th>
<th>(25-44)</th>
<th>%</th>
<th>(45-65)</th>
<th>%</th>
<th>&gt;65</th>
<th>%</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>2</td>
<td>25.00</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>2</td>
<td>25.00</td>
<td>4</td>
</tr>
<tr>
<td>1987</td>
<td>0</td>
<td>0.00</td>
<td>2</td>
<td>0.00</td>
<td>2</td>
<td>25.00</td>
<td>0</td>
<td>0.00</td>
<td>2</td>
<td>33.33</td>
<td>2</td>
<td>25.00</td>
<td>8</td>
</tr>
<tr>
<td>1988</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>1</td>
<td>12.50</td>
<td>2</td>
<td>40.00</td>
<td>1</td>
<td>16.67</td>
<td>0</td>
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<td>4</td>
</tr>
<tr>
<td>1989</td>
<td>0</td>
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<td>0</td>
<td>0.00</td>
<td>1</td>
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<td>2</td>
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<td>6</td>
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<td>0</td>
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<td>20.00</td>
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<td>2</td>
<td>0.00</td>
<td>8</td>
<td>100</td>
<td>5</td>
<td>100</td>
<td>6</td>
<td>100</td>
<td>8</td>
<td>100</td>
<td>29</td>
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<td>% tot.</td>
<td>0.00</td>
<td>6.90</td>
<td>27.59</td>
<td>17.24</td>
<td>20.69</td>
<td>27.59</td>
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### Distribution of serious injuries per groups of ages per year

<table>
<thead>
<tr>
<th>YEAR</th>
<th>[0-5]</th>
<th>%</th>
<th>(6-14)</th>
<th>%</th>
<th>(15-24)</th>
<th>%</th>
<th>(25-44)</th>
<th>%</th>
<th>(45-65)</th>
<th>%</th>
<th>&gt;65</th>
<th>%</th>
<th>SUM</th>
</tr>
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<tbody>
<tr>
<td>1986</td>
<td>1</td>
<td>12.50</td>
<td>4</td>
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<td>42</td>
<td>16.54</td>
<td>40</td>
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<td>22</td>
<td>20.75</td>
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<td>14.29</td>
<td>117</td>
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<td>6</td>
<td>24.00</td>
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<td>48</td>
<td>22.97</td>
<td>32</td>
<td>30.19</td>
<td>16</td>
<td>28.57</td>
<td>186</td>
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<tr>
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<td>12.50</td>
<td>5</td>
<td>20.00</td>
<td>59</td>
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<td>52</td>
<td>24.88</td>
<td>17</td>
<td>16.04</td>
<td>10</td>
<td>17.86</td>
<td>144</td>
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<tr>
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<td>3</td>
<td>37.50</td>
<td>4</td>
<td>16.00</td>
<td>35</td>
<td>13.78</td>
<td>38</td>
<td>18.18</td>
<td>18</td>
<td>16.98</td>
<td>16</td>
<td>28.57</td>
<td>114</td>
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<td>8</td>
<td>100</td>
<td>25</td>
<td>100</td>
<td>254</td>
<td>100</td>
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<td>106</td>
<td>100</td>
<td>56</td>
<td>100</td>
<td>658</td>
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<tr>
<td>% tot.</td>
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<td>3.80</td>
<td>86.60</td>
<td>31.76</td>
<td>16.11</td>
<td>8.51</td>
<td>100</td>
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</table>

### Distribution of slight injuries per groups of ages per year

<table>
<thead>
<tr>
<th>YEAR</th>
<th>[0-5]</th>
<th>%</th>
<th>(6-14)</th>
<th>%</th>
<th>(15-24)</th>
<th>%</th>
<th>(25-44)</th>
<th>%</th>
<th>(45-65)</th>
<th>%</th>
<th>&gt;65</th>
<th>%</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>30</td>
<td>37.97</td>
<td>46</td>
<td>31.29</td>
<td>264</td>
<td>30.66</td>
<td>326</td>
<td>31.74</td>
<td>184</td>
<td>34.26</td>
<td>50</td>
<td>35.97</td>
<td>900</td>
</tr>
<tr>
<td>1988</td>
<td>7</td>
<td>8.86</td>
<td>24</td>
<td>16.33</td>
<td>147</td>
<td>17.07</td>
<td>168</td>
<td>16.36</td>
<td>57</td>
<td>10.61</td>
<td>15</td>
<td>10.79</td>
<td>418</td>
</tr>
<tr>
<td>1989</td>
<td>16</td>
<td>20.25</td>
<td>29</td>
<td>19.73</td>
<td>158</td>
<td>18.35</td>
<td>182</td>
<td>17.72</td>
<td>121</td>
<td>22.53</td>
<td>25</td>
<td>17.99</td>
<td>531</td>
</tr>
<tr>
<td>1990</td>
<td>14</td>
<td>17.72</td>
<td>32</td>
<td>21.77</td>
<td>175</td>
<td>20.33</td>
<td>191</td>
<td>18.60</td>
<td>103</td>
<td>19.18</td>
<td>29</td>
<td>20.86</td>
<td>544</td>
</tr>
<tr>
<td>SUM</td>
<td>79</td>
<td>100</td>
<td>147</td>
<td>100</td>
<td>861</td>
<td>100</td>
<td>1027</td>
<td>100</td>
<td>537</td>
<td>100</td>
<td>139</td>
<td>100</td>
<td>2790</td>
</tr>
<tr>
<td>% tot.</td>
<td>2.83</td>
<td>5.27</td>
<td>30.86</td>
<td>36.81</td>
<td>19.25</td>
<td>4.98</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the most accident prominent for both cities with the accidents occurring during this period being 41.35% in Nicosia and 39.00% in Limassol (percentages of the total).

Table 4 shows the drivers age and sex. In Nicosia 35.56% of the drivers involved in accidents during the study period are between 25-44 and 33.08% are between 15-24. It has not been attempted to reach any conclusions about the relation between sex and accidents judging only from the absolute number of participants without any knowledge concerning the distribution of driving licences between sexes. In absolute numbers, in Nicosia 64.05% of the involved drivers were male 64.05% and 35.95% female, while in Limassol the corresponding numbers are 68.53% and 31.47%.

In Limassol table 5 the picture is different with the ages between 15-24 participating in 41.76% of all the accidents being followed by the ages 25-44 with 32.84%. The group of ages between 15-24 possess the first place in the involvement rate in Limassol and the second in Nicosia because a high percentage of them uses two-wheeled vehicles (mainly motorbikes-motorcycles) which are vulnerable and are more frequently involved in accidents. However in order to reach safe conclusions concerning the behaviour of the drivers as a cause of the accidents the distribution of ages and driving licences should be known.

In table 6 the distribution of injuries per age group is presented. In Nicosia the highest number of fatal injuries belongs in the groups 15-24 and >65. The first group due to the fact that mainly uses two-wheeled vehicles and the second due to their high physical vulnerability because of their age. Most of the serious injured belong in the age group 15-24 in percentage 36.80% and most of the slightly injured in the age group 25-44 in percentage 36.81%.

In Limassol the ages 15-24 possesses the first place among the injuries categories (fatal, serious, slight) with 38.9% fatal, 42.53% serious and 40.06% slight.

Table 7: Distribution of injured pedestrians and accident weight in Limassol.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Total injured per.</th>
<th>Injured pedestrians</th>
<th>% of total</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Acc. weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>382</td>
<td>22</td>
<td>5.76</td>
<td>1</td>
<td>2</td>
<td>19</td>
<td>74</td>
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<td>1987</td>
<td>362</td>
<td>29</td>
<td>8.01</td>
<td>1</td>
<td>9</td>
<td>19</td>
<td>109</td>
</tr>
<tr>
<td>1988</td>
<td>359</td>
<td>20</td>
<td>5.57</td>
<td>0</td>
<td>5</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>1989</td>
<td>411</td>
<td>45</td>
<td>10.95</td>
<td>2</td>
<td>15</td>
<td>28</td>
<td>193</td>
</tr>
<tr>
<td>1990</td>
<td>442</td>
<td>47</td>
<td>10.63</td>
<td>2</td>
<td>15</td>
<td>30</td>
<td>150</td>
</tr>
<tr>
<td>SUM</td>
<td>1956</td>
<td>163</td>
<td>8.33</td>
<td>6</td>
<td>46</td>
<td>111</td>
<td>566</td>
</tr>
</tbody>
</table>

Special attention must be paid to the road accidents involving pedestrians because they result in high percentages of fatal injuries having 34.48% fatal injuries (of the total) in Nicosia and 33.33% in Limassol. The second more vulnerable category are the two-wheeled drivers. This is clearly stated in tables 7&8 where it is seen that 8.33% of the injured are pedestrians and 47.03% are two-wheeled drivers. The correspondent percentages in Nicosia are 5.26% and 26.08%.
Table 8: Distribution of injured pedestrians and accident weight in Limassol.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Total injured per.</th>
<th>Injured motorbikes and motorcyclists</th>
<th>% of total</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Acc. weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>382</td>
<td>163</td>
<td>42.67</td>
<td>0</td>
<td>26</td>
<td>137</td>
<td>267</td>
</tr>
<tr>
<td>1987</td>
<td>362</td>
<td>169</td>
<td>46.69</td>
<td>0</td>
<td>23</td>
<td>146</td>
<td>261</td>
</tr>
<tr>
<td>1988</td>
<td>359</td>
<td>178</td>
<td>49.58</td>
<td>3</td>
<td>26</td>
<td>149</td>
<td>414</td>
</tr>
<tr>
<td>1989</td>
<td>411</td>
<td>189</td>
<td>45.99</td>
<td>1</td>
<td>37</td>
<td>151</td>
<td>381</td>
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<tr>
<td>1990</td>
<td>442</td>
<td>221</td>
<td>50.00</td>
<td>2</td>
<td>37</td>
<td>182</td>
<td>457</td>
</tr>
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<td>920</td>
<td>47.03</td>
<td>6</td>
<td>149</td>
<td>765</td>
<td>1780</td>
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</tbody>
</table>

In both cities 95% of the accidents take place under dry conditions and the remaining 5% in wet conditions.

One of the most important distributions concerns the accidents causes as they are recorded by the Police.

In Nicosia: a) Crossing without due care at road junction (uncontrol), 28.29% b) Failing to comply with traffic sign or signal, 22.38% c) Turning right without due care. d) Following too closely behind another vehicle 8.46%

In Limassol: a) Failing to comply with traffic sign or signals 48.24% b) Turning right without due care 14.17% c) Overtaking improperly on offside. From the grouping of the causes and the factors for both cities it has been shown that in Nicosia the distribution of the responsibility for the accidents is 95.09% on the drivers and 4.3% on the pedestrians while in Limassol the correspondent numbers are 92.69% and 6.43%. The accidents causes with the higher accident weight are a) Failing to comply with traffic sign or signal and b) Turning right without due care.

It has to be stated that in this stage of the analysis the inadequacies of the road network (Lighting, Signing etc.) were not taken into account. Therefore the above conclusions do not contain any collaboration of the initial Police recordings.

The distribution of vehicles types is also very important because it indicates the level of involvement for each vehicle type. Thus in Nicosia the percentages for each vehicle type are: private cars 52.42% , light goods vehicle up to 2 tons (L Rovers, pick-ups etc.) 14.38%, motorbikes 9.45%, motorcycles 5.32% while in Limassol the correspondent percentages are: private cars 42.82%, motorbikes 18.06%, light goods vehicle up to 2 tons 12.32% and motorcycles 10.12%.

The grouping per vehicle type for accidents with injuries of the previous distribution showed that motorbikes possess the first place in the involvement rates for both cities with percentages 57.98% and 48.49% for Nicosia and Limassol correspondingly.

Injured persons and accidents weights for the most important vehicle types which were involved in accidents in Nicosia are recorded in table 9.

Motorcycles have higher accident weight for both cities. That confirms the fact that they are the most vulnerable vehicles.

The next step in the analysis is regarded to be the most crucial because it concerns the analysis of the intersections with more than 25 accidents during the study period. This condition was satisfied by 85 intersections in Nicosia and 34 in Limassol which clearly states that Nicosia faces more serious accidents problem.

For each intersection a table was constructed including the accidents, injuries, accident weights and the causes for the accidents that occurred at this particular intersection. In
Table 9: Vehicle type in relation to injured persons

<table>
<thead>
<tr>
<th>Motorcycles</th>
<th>Acc. injur. per.</th>
<th>Acc. matt. dam.</th>
<th>Sum</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Acc.weig.</th>
<th>Av.ac.weig.</th>
</tr>
</thead>
<tbody>
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<td>88</td>
<td>29</td>
<td>117</td>
<td>1</td>
<td>26</td>
<td>60</td>
<td>235</td>
<td>2.67</td>
</tr>
<tr>
<td>1987</td>
<td>154</td>
<td>50</td>
<td>204</td>
<td>0</td>
<td>28</td>
<td>120</td>
<td>260</td>
<td>1.69</td>
</tr>
<tr>
<td>1988</td>
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<td>22</td>
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<td>0</td>
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<td>88</td>
<td>263</td>
<td>2.25</td>
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<td>2</td>
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<td>6.78</td>
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<td>698</td>
<td>4</td>
<td>141</td>
<td>467</td>
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</table>

<table>
<thead>
<tr>
<th>Motorcycles</th>
<th>Acc. injur. per.</th>
<th>Acc. matt. dam.</th>
<th>Sum</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Acc.weig.</th>
<th>Av.ac.weig.</th>
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<td>177</td>
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</tr>
<tr>
<td>1987</td>
<td>122</td>
<td>40</td>
<td>162</td>
<td>2</td>
<td>58</td>
<td>82</td>
<td>462</td>
<td>3.79</td>
</tr>
<tr>
<td>1988</td>
<td>47</td>
<td>18</td>
<td>65</td>
<td>1</td>
<td>7</td>
<td>41</td>
<td>121</td>
<td>2.57</td>
</tr>
<tr>
<td>1989</td>
<td>55</td>
<td>6</td>
<td>61</td>
<td>1</td>
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<td>186</td>
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<td>14</td>
<td>55</td>
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<td>1037</td>
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</table>

<table>
<thead>
<tr>
<th>Cars</th>
<th>Acc. injur. per.</th>
<th>Acc. matt. dam.</th>
<th>Sum</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Acc.weig.</th>
<th>Av.ac.weig.</th>
</tr>
</thead>
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<td>4060</td>
<td>2</td>
<td>80</td>
<td>650</td>
<td>1140</td>
<td>1.20</td>
</tr>
<tr>
<td>1988</td>
<td>451</td>
<td>1570</td>
<td>2021</td>
<td>3</td>
<td>46</td>
<td>268</td>
<td>633</td>
<td>1.40</td>
</tr>
<tr>
<td>1989</td>
<td>612</td>
<td>2335</td>
<td>2947</td>
<td>1</td>
<td>77</td>
<td>363</td>
<td>793</td>
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</tr>
<tr>
<td>1990</td>
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<td>2055</td>
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<td>2</td>
<td>52</td>
<td>336</td>
<td>686</td>
<td>1.19</td>
</tr>
<tr>
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<td>10443</td>
<td>13487</td>
<td>8</td>
<td>321</td>
<td>1884</td>
<td>3849</td>
<td>1.26</td>
</tr>
</tbody>
</table>
addition for some of the intersection where available traffic data existed the risk factor for each intersection was estimated using the formula:

$$U_r = \frac{2z}{365(Q_1 + Q_2 + \ldots + Q_n)} \cdot 10^8$$

where $z$ = Number of accident in year
$Q_1, Q_2, \ldots, Q_n$ = Traffic flows for each arm of the intersection (veh/day)

Studying the previous data in conjunction with the maps and sketches of the intersections very useful conclusions will be extracted which might lead to proposals for remedial measures. The research on the intersections has not yet been completed. The analysis concludes with a reference at the road accidents occurring at road sections .Table 2 shows that accidents involving material damages and the ones involving injuries follow the same pattern for each city having a sudden increase of 15% in Limassol and 10% in Nicosia during 1989 and lying in the same 1989 levels during 1990.

Conclusions

1. The higher number of accidents either involving injuries or material damages takes place at intersections. However the accidents occurring at road sections have greater average weights even though this difference is minor.
2. The most important problems concerning road safety occur at intersections and especially in the centre of Nicosia. It is worth noting that in Limassol 41.18% of the most critical intersections are lying across the central arterial which crosses through almost the whole city .(Arh. Makariou III). The fact that 5 of the 6 roundabouts of the ring road which leads to the suburbs of Limassol and the cities of Nicosia and Pafos are critical is also very important.
3. The most vulnerable categories are the pedestrians and the two-wheeled drivers in both cities. Especially in Limassol the two-wheeled drivers come first among all the categories of injured persons and this could be related to the fact that the most critical ages of injured persons are between 15-24. Most of the injured pedestrians in Nicosia occur at intersections while in Limassol at road sections even though the difference between those numbers is very small.
References

1. Accident and traffic data bases, Department of Public Works, Nicosia, 1991 - 92.
PLENARY OPENING SESSION - II
SAFETY RECOMMENDATIONS - THE ENGINE THAT DRIVES CHANGE

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Abstract

The National Transportation Safety Board (NTSB) considers the recommendations it makes to prevent accidents and improve the safety of the United States transportation system to be its most important product.

In its 25 year history the NTSB has made almost 9,000 safety recommendations covering needed improvements in all the modes of transportation to more than 1,250 recipients. These recommendations are made to anyone the NTSB believes can make the change that is necessary to improve safety. Recommendations have been directed to Federal, State and local government agencies, private transportation companies, labor unions, trade associations and others.

Overall, more than 80 percent of the NTSB's safety recommendations have been accepted by the recipients and the changes called for have been implemented. This has had a very significant positive impact on the safety of the U.S. transportation system. The NTSB is very proud of this record. The changes that have taken place as a result of the NTSB's recommendations have saved thousands of lives and prevented many accidents.

How has the NTSB achieved such a good record? The basic foundation and most important reason for this achievement is the NTSB's independence. This independence lends the NTSB credibility. Recipients of the NTSB's recommendations are more willing to carefully and seriously consider taking the action recommended. The second essential reason for the NTSB's credibility is the highly competent, technical qualifications of its investigators and the thoroughness of its investigations and studies. The NTSB also is very careful and prudent in making its recommendations. Each proposed recommendation is carefully evaluated to make sure it is practical, feasible and capable of being implemented. The credibility of the NTSB has grown over the years, and along with that has come an increase in the acceptance rate of the recommendations.
This paper will describe the NTSB's safety recommendation program, how it achieves improved safety, and its important elements, such as the Most Wanted Safety Recommendation program and the Safety Recommendation Information System.

Introduction

Over the years the NTSB has directed recommendations to more than 1,250 different addressees. The number one recipient of its almost 9,000 recommendations, as would be expected, is the U.S. Department of Transportation (DOT) and its modal administrations, such as the Federal Aviation Administration (FAA), the Federal Railroad Administration, the Federal Highway Administration or the Coast Guard. Because of the differences in the operation, regulatory scenario and historical development in each mode of transportation, recommendations are directed to different segments of the industry in each mode.

In the U.S., each transportation industry operates in a different regulatory climate. For example, the aviation industry is heavily regulated at the Federal level by the FAA, while in the highway mode, much more control for safety lies with the 50 States. Because of these differences, the NTSB sends its recommendations to different agencies and levels of government in each mode. In aviation, most of the NTSB recommendations are directed to the FAA, while to improve highway and traffic safety most recommendations are directed to State governments and to the individual manufacturers of vehicle. In the marine, railroad, hazardous materials and pipeline industries, a mixture of various agencies and companies receive NTSB recommendations.

The highest percent of the NTSB's recommendations have addressed aviation safety. Table 1 provides a breakdown of the number and percentage of recommendations covering each mode of transportation.
Table 1
Safety Recommendations Issued by Mode (since 1967)

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<tr>
<th>MODE</th>
<th>ISSUED</th>
<th>PERCENT</th>
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<tbody>
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<td>Highway</td>
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<td>16.6</td>
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<td>Intermodal</td>
<td>179</td>
<td>2.0</td>
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<tr>
<td>Marine</td>
<td>1777</td>
<td>19.7</td>
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<tr>
<td>Pipeline</td>
<td>980</td>
<td>10.9</td>
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<td>17.1</td>
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<tr>
<td>TOTALS</td>
<td>9000</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source of Recommendations

The recommendations made by the NTSB come from three main sources. First, recommendations are proposed by NTSB field investigators who investigate more than 2,000 civil aviation accidents each year. These accidents primarily involve small general aviation aircraft. The proposed recommendations that come from these investigations are generally focused on a mechanical problem with a particular aircraft or a safety problem applicable only to one airport or location. However, in some instances, these recommendations do have national implications.

Second, the most visible, and wide-sweeping, are those recommendations that result from the investigation of major accidents. For example, the investigation of aircraft collisions at Atlanta, Georgia; Detroit, Michigan and Los Angeles, California (NTSB 1991a, 1991b, 1991c) resulted in broad-reaching recommendations to prevent runway incursions. Recommendations do not have to wait for the completion of an investigation. They can, and often are, issued at any time during the investigation when it becomes clear to investigators that a safety problem needs immediate attention.
A third source of safety recommendations are the safety studies conducted in all modes by the NTSB. The recommendations that result from studies generally have national implications and in some instances demand greater respect, primarily because they are based on many accidents that occurred over a long period of time. For example, the 1989 study on the safety of passenger vessels operating from U.S. ports contained 41 recommendations addressed to the U.S. Coast Guard and 6 other agencies or associations (NTSB 1989). The recommendations were based on data and information the NTSB had developed through its investigation of many passenger vessel accidents over its 25 year history.

In addition, the NTSB can and does issue recommendations whenever and wherever it becomes aware of a safety problem in the transportation system.

Effectiveness of NTSB Recommendations

Overall, 82 percent of the 9,000 NTSB safety recommendations have been accepted by the recipients and the changes called for have been, or are being, implemented. The implementation of these recommendations have prevented many accidents and saved thousands of lives. For example, after a series of crashes of large air carrier aircraft into terrain in the early 1970's, the NTSB called for the installation of ground proximity warnings systems (GPWS) on all large air carrier aircraft (NTSB 1971). The implementation of GPWS has virtually eliminated this type of accident in the U.S.

Another example was the recommendation the NTSB sent to each State calling for the raising of the legal purchase age of alcoholic beverages to 21 years in all States (NTSB 1982). This began a National debate that led to the passage of such laws in all States. Studies have shown that more than 12,000 lives have been saved as a result.

The basic foundation and most important reason for the high rate of acceptance of its recommendations is the NTSB's independence. This independence is a major reason for the NTSB's high credibility. Recipients of the NTSB's recommendations are more willing to carefully and seriously consider taking the action recommended. The second essential reason for the NTSB's credibility is the highly competent, technical qualifications of its investigators and the thoroughness of its investigations and studies. The NTSB also is very careful and prudent in making its recommendations. Each proposed recommendation is carefully evaluated to make sure it is practical,
feasible and capable of being implemented. The credibility of the NTSB has grown over the years, and along with that has come an increase in the acceptance rate of the recommendations. It should be pointed out that all NTSB recommendations, and the reports that justify them, are made public at the time they are issued. In fact, much of the NTSB's work on an investigation or study is done in public and with the cooperation of the interested parties. Hearings to gather evidence in an investigation, and meetings of the Board to adopt recommendations are open to the public and the media.

Safety Recommendation Followup Program

There is another very important ingredient that helps account for the high rate of acceptance of the NTSB's recommendations. That is the comprehensive and formal recommendation followup program conducted by NTSB. The important work conducted by the NTSB investigators does not, by itself, improve safety. Nor does issuing a recommendation improve safety. It is the implementation of the recommendation that actually brings about the change that leads to improved safety. The NTSB considers its activities designed to achieve implementation of its recommendations to be one of its most important functions. To oversee this activity, the NTSB has an Office of Safety Recommendations. One of its main functions is to work toward the highest rate of acceptance of NTSB recommendations as possible.

Since 1967, the NTSB has issued almost 9,000 safety recommendations to more than 1,250 addressees. These addressees include the U. S. Department of Transportation, other Federal agencies, State governments, private transportation related companies, labor unions, transportation trade organizations and others. Because of its preeminent role in the safety of the transportation system, 58 percent of NTSB's recommendations have been addressed to the U.S. DOT and its modal administrations. The NTSB also uses different approaches and strategies in its aggressive program to obtain implementation of its recommendations. The DOT is the only recipient of NTSB recommendations that is required to respond formally to NTSB. By law, the DOT must, within 90 days, advise the NTSB what action it plans to take concerning each recommendation or explain why it is not planning to accept the recommendation. Even though other recipients, such as State Governors or private airlines or railroads are not required to formally respond, the NTSB has been quite successful in obtaining a response. One of the reasons
is the NTSB's willingness to advise the public and the Congress that no reply has been received. No organization involved in public transportation wants to be labeled as unwilling to address safety concerns.

Status of Recommendations

When the NTSB receives an answer to its recommendations from a recipient, a thorough review of the action planned is undertaken and a status is assigned to each recommendation. The recipient is then advised of the status. The various status categories are listed in Table 2.

The level and method of followup activity is based, to a great extent, on the assigned status. Since the assignment of an "unsatisfactory response" can have an unwanted impact on the image of an agency or company, recipients generally attempt to comply with the intent of the recommendation, either by doing exactly what the NTSB recommends or suggesting other actions to solve the safety problem identified by the NTSB.

One recently implemented strategy for following up recommendations involves a meeting of the NTSB Chairman and the heads of the DOT administrations, trade associations and companies to discuss important recommendations that have not been implemented. These high level meetings have led to followup meetings at the staff level. In some instances, such as with the AMTRAK passenger train company, meetings are scheduled quarterly to discuss progress on implementing the recommendations or to clear up misunderstandings that could occur. There are occasions where the recipient may not fully grasp exactly what the NTSB would like accomplished. These meetings have helped clarify the exact intent of various recommendations and resulted in safety improvements, where in the past no action would have been taken primarily because of a misunderstanding. In the past 2 years, more than 80 meetings have taken place, at which more than 1,200 of the 1,900 open safety recommendations have been discussed.

Safety Recommendations Information System

Prior to 1976, these safety recommendations were tracked only through maintenance of hard copy files. By 1977, the Safety Board had issued 2,300 safety recommendations and the manual/hard copy filing procedures were fast becoming obsolete.
Table 2

Safety Recommendations Status Classifications

Open--Await Response:
Safety recommendation issued and no response received from addressee or response does not specifically address the recommendation.

Open--Response Received:
A response has been received from addressee but the evaluation has not yet been approved by the Board Members.

Open--Acceptable Response:
Response by addressee indicates a planned action which would comply with the safety recommendation when implemented.

Open--Acceptable Alternate Response:
Response by addressee indicates an alternative plan or implementation program which would satisfy the objective of the safety recommendation when implemented.

Open--Exceeds Recommended Action:
Addressee responds with a proposed action that is both timely and goes beyond the actual recommended action.

Open--Unacceptable Response:
The addressee responds by expressing disagreement with the need outlined in the recommendation. There is enough supporting evidence to ask the addressee to reconsider the position taken.

Closed--Acceptable Action:
Action on the safety recommendation has been completed by the addressee. The action complies with the safety recommendation.

Closed--Acceptable Alternate Action:
Addressee responds with an alternative course of action which is completed and meets the objectives of the safety recommendation.

Closed--Exceeds Recommended Action:
Addressee responds with a completed action that is both timely and goes beyond the actual recommended action.

Closed--Unacceptable Action:
The addressee responds by expressing disagreement with the need outlined in the safety recommendation. There is no further evidence to offer and it is concluded that further correspondence on or discussion of the matter would not change the addressee’s position.

Closed--Unacceptable Action-No Response Received:
Addressee fails to provide a response to the safety recommendation even after a reminder has been communicated.

Closed--No Longer Applicable:
The recommended actions have been overtaken by events.

Closed--Reconsidered:
Addressee rejects the safety recommendations and supports the rejection with a rationale in which the Safety Board concurs; or in situations where the recipient of a recommendation was in compliance before the recommendation was issued.

Closed--**CURRENT STATUS**/Superseded:
Applicable to safety recommendations held in any open status. To be applied in instances where a new more appropriate safety recommendation is issued which includes the necessary elements of the existing safety recommendation to be closed. The listing of the current status before the “superseded” will provide historical information for future reference. A new evaluation of the current status should be made prior to any closeout action.

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The need to track all safety recommendations issued by the NTSB was included in the legislation (Public Law 93-633) setting up the independent safety board -- the Board is required by that legislation to provide an annual report to the Congress on its activities, including what action has been taken as a result of its safety recommendations. Further, as more accidents occurred and additional recommendations were issued, it became vital to provide a discussion of what action the Board had previously taken on recurring safety issues. As the number of recommendations grew and the amount of correspondence on each recommendation increased, it became apparent that the information would have to be digitized.

In 1976, work was begun on a computerized Safety Recommendations Information System (SRIS), which was to be designed to include all pertinent data related to transactions and activities surrounding each of the NTSB's recommendations.

The SRIS was designed as an interactive database which would allow searches of the text databases by either any number of assigned "key words," or by a global search by a character string. The SRIS was also constructed to allow for the development of trend information regarding the status of the recommendations, i.e., the number of recommendations successfully acted on by individual addressees, by mode, or other groupings. For example, the rate of acceptance of NTSB recommendations by the U.S. DOT modal administrations varies considerably. The total acceptance rate for DOT is 82 percent, varying from 87 percent by the Federal Highway Administration to a low of 74 percent for the Coast Guard. Table 3, generated from the data in the SRIS, shows the acceptance rate for each administration.

The SRIS provides for the digitizing of 31 different informational fields including: date and location of the accident, make and model of the vehicle in the accident, the operator, mode of operation, safety recommendation number, date of issue of safety recommendation, date of addressee response(s), date of NTSB followup action, date of closeout, NTSB assigned status, and NTSB classification. These fields are linked and each recommendation can be accessed through any of the fields. Preformatted reports have been programmed for ease of use; but individualized reports can be constructed by the user.

The SRIS makes it possible for staff of the Office of Safety Recommendations to provide Board members and accident investigators information on previously addressed issues at the time of a "Go-Team" launch to an
<table>
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<tr>
<th>MODE</th>
<th>CEX</th>
<th>CAA</th>
<th>CAAA</th>
<th>CUA</th>
<th>CUAS</th>
<th>CR</th>
<th>CS</th>
<th>CNLA</th>
<th>Total Closed</th>
<th>OAA</th>
<th>OAAR</th>
<th>OUR</th>
<th>ORR</th>
<th>OAR</th>
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<td>25</td>
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<td>14</td>
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<td>220</td>
<td>405</td>
<td>1984</td>
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</tr>
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</table>

**Definition of Status Assignments:**
- **CEX:** Closed—Exceeds Recommended Action
- **CAA:** Closed—Acceptable Action
- **CAA:** Closed—Acceptable Alternate Action
- **CUA:** Closed—Unacceptable Action
- **CUAS:** Closed—Unacceptable Action/Superseded
- **CR:** Closed—Reconsidered
- **CS:** Closed—Superseded
- **CNLA:** Closed—No Longer Applicable
- **OAA:** Open—Acceptable Response
- **OAAR:** Open—Acceptable Alternate Response
- **OUR:** Open—Unacceptable Response
- **ORR:** Open—Response Received
- **OAR:** Open—Await Response
## Table 3 (continued)

National Transportation Safety Board  
Status of Safety Recommendations  
by DOT Administrations  
November 1992

<table>
<thead>
<tr>
<th>MODE</th>
<th>CEX</th>
<th>CAA</th>
<th>CAAA</th>
<th>CUAS</th>
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<td>126</td>
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<td>110</td>
<td>992</td>
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</table>

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accident. For example, when the NTSB was notified of the U.S. Air, F-28 crash at La Guardia Airport in a snowstorm on March 22, 1992, the investigator-in-charge was provided with a printout, before he left for the scene of the accident, of all past recommendations, and the accidents they came from, concerning the F-28, La Guardia Airport, and the problem of aircraft icing.

The system also allows staff to provide the Board members, the Congress, the media, the public, and investigators from other countries with statistical information regarding the success of our recommendations. Figure 1 shows one of the uses made of the statistical data retrieved from the SRIS. Data in the SRIS are publicly available upon request and plays an important role in the NTSB's activities to achieve implementation of its recommendations.

One of the most important uses of the SRIS is in the development of new safety recommendations. The SRIS provides a detailed, historical record of the actions the NTSB has taken, and the action, or lack of action, on the part of recipients of the past recommendations. This information assists the investigator by providing a proper perspective of previous steps taken to address a particular safety issue.

One of the fields listed for the SRIS is "Classification." This particular piece of information was added to the safety recommendations in the early 1970's. The Board decided then that the relative sense of urgency for each of the individual safety recommendations needed to be conveyed to the recipient and to provide guidance for NTSB followup, and a system of classification was developed. The system arrived at includes 3 levels of urgency:

CLASS I: Urgent Action - To be used where it is determined that completion of action is necessary to avoid imminent loss due to similar accidents that could occur under the same circumstances if a deficiency is not corrected.

CLASS II: Priority Action - To be used where it is determined that a high priority for action should be set to avoid a probable loss due to similar accidents that could occur under the same circumstances if a deficiency is not corrected.
Figure 1
Example of Data Retrieved from SRIS

National Transportation Safety Board
Report Date: 11/05/92

Report: AAR-86-06
Accident Date: August 25, 1985
Accident City: Auburn
Accident State: ME

Recommendation Number(s)
A-86-109

Abstract:
The Investigation of 3 recent commuter air carrier accidents have prompted the National Transportation Safety Board's concern about several significant safety issues. On August 25, 1985, Bar Harbor Airlines Flight 1808, a Beech Model 99, crashed during an instrument landing system (ILS) approach to Auburn-Lewiston Airport, Auburn, Maine. The airplane struck trees at an elevation of 345 feet mean sea level (MSL) in a wings-level attitude 4,000 feet from the end of the runway threshold and 440 feet to the right of the extended runway centerline; all eight persons aboard were fatally injured. On September 23, 1985, Henson Airlines Flight 1517, a Beech B99, crashed during an ILS approach to Shenandoah Valley Airport, Weyers Cave, Virginia. The airplane struck trees at an elevation of 2,400 feet MSL in a wings-level attitude about 6 miles east of the airport; all 14 persons aboard were fatally injured. On March 13, 1986, Simmons Airlines Flight 1746, an Embraer EMB-110P1, crashed during an ILS approach to Phelps Collins Airport, Alpena, Michigan. The airplane struck trees at an elevation of 724 feet MSL in a wings-level attitude about 1.5 miles from the end of the runway threshold and about 300 feet to the left of the extended runway centerline; three of the nine airplane occupants were fatally injured. All 3 accidents involved scheduled domestic passenger flights operating under 14 CFR Part 135.

Recommendation Number: A-86-109
Date of Issue: October 9, 1986
NTSB Status: Closed--Acceptable Action
Closeout Date: June 10, 1992

Recommendation Subject:
The NTSB recommends that the Federal Aviation Administration: Amend 14 CFR 135.153 to require after a specified date the installation and use of Ground Proximity Warning Devices in all multiengine, turbine-powered fixed-wing airplanes, certificated to carry 10 or more passengers.

Addressee: FAA
Date of Response: 01/08/1987
The FAA initiated a regulatory project for the development of a Notice of Proposed Rulemaking (NPRM) for a ground proximity warning system for 14 CFR 135 operators. The rationale and requirements for the NPRM have been finalized and will be presented to the Regulatory Review Board in early 1987.

***A synopsis of each exchange of correspondence would follow in chronological order to the final closeout letter to the Addressee.***
CLASS III: Longer Term Action - To be used where it is determined that an immediate or near future similar accident is not likely if an identified deficiency is not corrected, or where the desired action cannot reasonably be expected to be accomplished within 2 years.

The Board members determine the classification to be applied to each recommendation at the time of adoption.

As would be expected, only 9 percent of the NTSB's recommendations are classified as "Urgent". Eighty six percent are classified "Priority" and 5 percent "Longer Term".

"Most Wanted" Safety Recommendations Program

In the Fall of 1990, the NTSB adopted a formal program to highlight certain transportation safety issues that the Board believed required the highest visibility and the strongest followup activity. The program as adopted by the Board was named the "Most Wanted" Safety Recommendations Program.

While the NTSB considers all of its safety recommendations to be important, it does realize that some will have a greater impact on reducing transportation accidents than others. A transportation safety issue can be considered for placement on the "Most Wanted" list if the issue will impact/enhance safety on a national transportation system level; the issue has a high level of public visibility/interest, i.e., the completion of the recommended action will build a more positive or secure view of the national transportation system in the eyes of the public; the recommended action can be completed in a reasonable period of time; and there has been consideration of previous loss of life/property, potential for future loss of life/property, public risk exposure, and of internal Board processes.

The original list contained 18 transportation safety issue areas in which the Board had issued safety recommendations that were then considered in an "open" status. These issues constituted what the Board believed to be those transportation safety topics requiring the highest priority actions by government and industry. The issue areas on the "Most Wanted" list are pursued and highlighted through the following activities: Public awareness activities, i.e., press conferences and releases, media interviews with both Board members and Safety Board staff, articles submitted to industry and trade periodicals by both Board members and staff;
testimony at the Federal, State, and local legislative hearings; speeches to trade and industry groups; rulemaking comments; and participation in workshops, seminars, and conferences.

The number of issues on the "Most Wanted" list is variable. However, the Board expressed a desire to limit the number so as not to dilute the impact of the program. The program was designed specifically to be multi-modal, but coverage is not necessarily balanced evenly by mode.

Procedurally, only the Board acting at an open meeting can place issues on the list or remove them from the list. Staff is to report semiannually on the progress of the various issue areas and make recommendations to the Board concerning the addition or removal of items from the list.

In the two years since its adoption, the program has proven very effective. Two issues have been removed from the list:

- Identification of pilots with substance abuse problems -- action by the Federal Aviation Administration (FAA); and
- Requirements for Ground Proximity Warning Systems on all commuter class aircraft -- action also by the FAA.

There are currently 17 issues on the "Most Wanted" Safety Recommendations Program list. These are shown in Figure 2.

Conclusion

Investigating accidents or conducting studies of transportation safety problem, in themselves, does not improve safety or prevent accidents from recurring; nor does the issuance of safety recommendations. Investigating accidents and issuing recommendations are just steps along the path change. It is only by the implementation of the recommendation, does real change take place. It is this change that makes the difference. This concept is well recognized by the NTSB. This leads to a very dedicated, active advocacy program by the NTSB. Only by undertaking such a program can the NTSB meet its goals of improving safety.
# MOST WANTED Transportation Safety Improvements

"... a program to increase the public's awareness of, and support for, action to adopt safety steps that can help prevent accidents and save lives."

<table>
<thead>
<tr>
<th>Action Needed by State Legislatures</th>
<th>Action Needed by the Research and Special Programs Administration (RSPA) and the Federal Railroad Administration (FRA)</th>
<th>Action Needed by the Department of Transportation (DOT)</th>
<th>Action Needed by the National Highway Traffic Safety Administration (NHTSA)</th>
<th>Action Needed by the Federal Aviation Administration (FAA)</th>
<th>Action Needed by the United States Coast Guard (USCG)</th>
<th>Action Needed by the Department of Transportation (DOT)</th>
<th>Action Needed by the Federal Aviation Administration (FAA)</th>
<th>Action Needed by the Federal Highway Administration (FHWA) and the States</th>
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<tr>
<td></td>
<td>- Strengthen Enforcement and Toxicological Testing Programs to Prevent Boating Accidents</td>
<td>- Study the relationship of Fatigue and Work/Rest Cycles in the Transportation Industry and Update Applicable Regulations</td>
<td>- Safer Transportation for Schoolchildren</td>
<td>- Require Testing of Aircraft to the Equivalent of Two Lifetimes of Use</td>
<td>- Require Uniform Collection, Handling, Processing, and Testing for Alcohol and Other Drugs</td>
<td>- Require Improved Braking for Transport Category Airplanes</td>
<td>- Improve Prevention of Accidents Caused by Fatigue, Alcohol, Drug Use, and Medical Problems</td>
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<td>Administrative Revocation of Driver's License</td>
<td>Action Needed by State Legislatures</td>
<td>Action Needed by the Federal Aviation Administration (FAA)</td>
<td>Action Needed by State Legislatures</td>
<td>Action Needed by the Federal Aviation Administration (FAA)</td>
<td>Action Needed by the United States Coast Guard (USCG)</td>
<td>Action Needed by the Department of Transportation (DOT)</td>
<td>Action Needed by the Federal Aviation Administration (FAA)</td>
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<td>- Pull Driver's License on the Spot of Anyone Failing or Refusing a Chemical Test for Alcohol</td>
<td>- Require a Railroad Collision Avoidance System and the Railroad Industry</td>
<td>- Install Collision Avoidance Systems for Airport Terminal Areas</td>
<td>- Require Testing of Aircraft to the Equivalent of Two Lifetimes of Use</td>
<td>- Upgrade Fire Detection and Control, Crew Communications and Training on Passenger Cruise Vessels</td>
<td>- Require Improved Braking for Transport Category Airplanes</td>
<td>- Improve Prevention of Accidents Caused by Fatigue, Alcohol, Drug Use, and Medical Problems</td>
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<td>Airport Runway Incursion</td>
<td>Positive Train Separation</td>
<td>Action Needed by the Federal Aviation Administration (FAA)</td>
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<td>Fishing Vessel Safety</td>
<td>Action Needed by the Federal Aviation Administration (FAA)</td>
<td>- Install Collision Avoidance Systems for Airport Terminal Areas</td>
<td>- Action Needed by the Department of Transportation (DOT)</td>
<td>- Action Needed by the Federal Aviation Administration (FAA)</td>
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<td>- Require Basic Lifesaving Equipment for Commercial Fishing Vessels</td>
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<td>Mandatory Seatbelt Use Laws</td>
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<td>- Require Occupants of Cars, Vans, and Light Trucks to Use Lap/Shoulder Belts</td>
<td>- Action Needed by the United States Coast Guard (USCG)</td>
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<td>Adjustable Upper Anchor Point For Lap/Shoulder Automobile Seatbelts</td>
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<td>- Increase Seatbelt Use and Effectiveness</td>
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<td>- Action Needed by the United States Coast Guard (USCG)</td>
<td>- Action Needed by the Federal Aviation Administration (FAA)</td>
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<td>Pipeline Excess Flow Valves</td>
<td>Action Needed by the Research and Special Programs Administration (RSPA) and the American Gas Association</td>
<td>- Action Needed by the United States Coast Guard (USCG)</td>
<td>- Action Needed by the United States Coast Guard (USCG)</td>
<td>- Action Needed by the Federal Aviation Administration (FAA)</td>
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<td>- Require the Installation of Excess Flow Valves in High Pressure Residential Natural Gas Distribution Systems</td>
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<td>- Action Needed by the Federal Aviation Administration (FAA)</td>
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</table>

*Figure 2*
REFERENCES


NEW TECHNOLOGY
A BROAD-BRUSH OUTLINE FOR THE RAILWAYS OF THE NEXT CENTURY

J.L. de Kroes

Delft University of Technology, The Netherlands

Introduction

The current mass mobility of populations creates considerable detrimental effects on human beings and their environment. The danger, the pollution, the excessive use both of raw material and of space, by the current transportation-systems not only affects us but also the coming generations. The only defence that we, as technical designers have, is that during the last century and a half, the requirements imposed by our society upon its transportation-systems have changed considerably. In the time when comparatively few "happy" people were mobile and had the ability to communicate and move their goods around, a managerial situation existed. Our society is in danger of collapse because of its own success in achieving such a high level of mobility.

It follows that our present mobility is not sustainable. Reducing mobility to a sustainable level would seem to be impossible without affecting the principles of our society; a society that requires consensus for its changes.

A second option enabling us to arrive at a sustainable level of mobility is to redesign our mobility-systems. This technical option is attractive at present, because the political detente between East and West frees much of the technical creativity of the military-industrial-complexes, enabling a fundamental and coherent redesign of our mobility systems. Even if one doubts the success of such an operation, one should still cooperate because the proven impracticability of this option could be the only way to obtain consensus in society for a drastic curbing of mobility.

In conceptual terms, our mobility-systems are 80 to 150 years old. Without redesign they cannot survive another century and therefore one should think now about the alternatives for the next century. The third option, to close ones eyes and allow the catastrophe to happen, is totally unjustified.

Re-design

The process of design requires the making of responsible choices. This process has two aspects. Firstly, comparing carefully the pro's and cons of the different alternatives. Secondly and equally as important, assuring oneself that all reasonable alternatives are taken into consideration.
In the choices for a design, there is clearly an ordered process. It starts with the determination of the main features or, using the analogy of the art of painting, the broad-brush outline. This is called the conceptual phase. This paper is, for reasons of length, limited to the conceptual phase of one mobility-system only, viz. mobility by rail. It should also be noted, that the same method can be used for starting the re-design of other mobility systems.

The design of the new mobility-systems should be based on a profound analysis of the pro's and cons of the existing systems. In the following table the different mobility-modes are reviewed against nine criteria. In every criterion, an arbitrary zero level is indicated by 0. With + and ++ more favorable scores are indicated, with - and -- less favorable ones. These rough indications are sufficient for this phase.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>A*</th>
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<th>M*</th>
<th>R*</th>
<th>S*</th>
<th>T*</th>
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<td>+</td>
<td>-</td>
<td>0</td>
<td>++</td>
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* A = Aviation  C = Coastal navigation  I = Inland-navigation
M = Motorway    R = Railway          S = Seagoing navigation
T = Telemobility

Telemobility scores best in this review. Mobility of this kind will therefore grow most rapidly. This rate of growth will slow down when nearly everyone can make contact with one another. This will be done regardless of whether they are stationary or mobile, not only communicating with voice and sound but also with printed data, text and (moving) pictures. More often than not, one or both communication partners are computers or computer networks. For this situation the term Telematics is invented. It also seems useful to have a term for the combined field; for this Telemobility seems appropriate. Inherent in the success of telemobility is the state of frequent re-designing during the last half century.

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Telemobility is already an indispensable support for all other kinds of mobility: e.g. for navigation and safety, for the tracking and tracing of vehicles and goods, for the handling of the many data systems (on paper or by other means) consistent with mobility.

The table shows also that all navigation systems score highly. A policy of substituting mobility on rail- and motorway for inland- and coastal navigation could therefore diminish the ill effects of the former systems. This substitution could be promoted by re-designing the navigation systems.

The design of new mobility systems suggests the use of novel, not yet developed technology. However, that is surely not the intention. The technology for these new systems should have proven its value either in mobility systems or in some other field of activity. It is not responsible to start a long and costly re-design and to discover at the end that the technology cannot be made available. As new mobility systems have to be introduced world-wide, the design requires world-wide deliberation; this adds considerably to the duration and cost.

The broad-brush outline and the underlying analysis can undoubtedly be improved by further research. The intention is to promote the idea of re-designing and to achieve the situation in which the study of new concepts of mobility systems in general, will become as accepted as it already is in telecommunications. This contribution seeks to indicate that there is a middle course between futuristic innovation with a technology that is not yet developed and the formulation of future scenarios that merely elaborate on already existing technology.

A broad-brush outline for the railways of the next century

The disadvantages of the present railroad system lays in its noise nuisance, space consumption and necessary governmental financial subsidies. In contrast with road vehicles the noise hindrance of the railways is not caused by propulsion but by the support and guidance of steel wheels by the steel rails. This concept has not been changed over 150 years.

The application of rubber wheels supported by a pavement of asphaltic concrete tracks can result in noise levels as low as those of trolleybusses. These new railroad vehicles are guided by a rail, a groove or a cable in the pavement. The combination of rubber wheels and asphaltic concrete will shorten the breaking distance considerably, facilitating a reduction in following distance between trains and tripling the capacity of the railway. Various disadvantages may be reduced and the doubling of tracks which is now under construction in The Netherlands, could have been avoided. Railway safety, which is already good in comparison with road safety, could also gain more benefits from this change.

In an economic sense, the change to rubber wheels and asphaltic concrete could increase the slopes and curves in railway tracks, thus reducing the space consumption in mountainous and densely populated areas and could
also reduce the public resistance against the construction of new, noisy railways.

An economic weakness in the present railway system is caused by the need for further transport over the roads and the transfer of goods and passengers in the change between the transportation modes. If the vehicles are fit for the railroad as well as for roads, they can be used for the further transport. Railroad vehicles may continue their travel as road vehicles, freight wagons may proceed as trailers to their final destination. It is also possible in the future to use road vehicles on the railroads. On longer hauls—such as over 50 km—a roadcar may use the railroad infrastructure.

The transfer from the old to the new system will be troublesome. For quite a time, the old and new systems will have to exist in parallel. Possibly, hybrid vehicles types fit for both railroads and roads will have to be developed. If the economic benefits are large enough, the transfer costs will be bearable. In telematics also, the introduction of radically new systems is associated with large costs.
Safe Design of Personal Rapid Transit Systems
J. Edward Anderson, PhD, P. E.
Boston University

Abstract
Safety issues have been a primary concern in the development of personal rapid transit since it started several decades ago. Safe design involves careful attention to all features of the design, such as the use of a hierarchy of fault-tolerant redundant control systems, bi-stable fail-safe switching, alternative power supplies, vehicle and passenger protection, and attention to the interaction of people with the system. Safety, together with reliability and adequate capacity, must be achieved while still making the system economically attractive, hence techniques to achieve these goals at minimum life-cycle cost are primary in PRT design. Building on theory of safe, reliable, and cost-effective design of PRT systems developed during the 1970s, in 1981 the author and his colleagues initiated design of a new PRT system, now called Taxi 2000. The paper describes the new design and reviews the principles of safe design, incorporated into Taxi 2000, which he believes will make this new system safer, more dependable, and more economical than existing modes of urban transportation.

Introduction
Following a decade of apparent dormancy, the concept of Personal Rapid Transit (PRT) is gaining attention largely because of two parallel $1,500,000 studies of PRT sponsored by the Northern Illinois Regional Transportation Authority (RTA). These studies are expected to lead to a demonstration PRT system in a suburb of Chicago in less than four years. The development of PRT had continued "behind-the-scenes" throughout the 1980s and a study of the status of PRT development by the Advanced Transit Association (1988) influenced the RTA decision to proceed.

PRT, as understood in this paper, is a system of small, fully automated vehicles that carry private groups of passengers in seated comfort nonstop between station pairs in a network of exclusive guideways. The stations are all "off-line," i.e., on by-pass guideways, thus permitting nonstop travel. The size of the vehicle has been much debated. Anderson (1986) gave ten arguments that led to the conclusion that the best size will accommodate three adults, or more people if the total mass is less than a given specification (now 340 kg). This recommendation was based on both sociological and
safety considerations and included a seating configuration, discussed below. PRT is essentially the application of the concept of an auto expressway to transit, and should attract trips for the same reasons: one can get where one wants to go in privacy and in substantially less time than in a system that stops at all stations.

Anderson (1984) showed that PRT can be derived from a system form of the equation for cost per passenger per unit of distance. The major cost element in an exclusive-guideway transit system is in the guideway itself. Many factors lead to minimization of its cost, the main one being the mass of the vehicles. Based on a study of dynamic loading of guideways by Snyder et al (1975), Anderson (1978) showed that the ratio of the mass per unit length of PRT to large-vehicle guideways was much smaller than would have been calculated based on static considerations alone. Later, it was found that the Taxi 2000 guideway mass per unit of length could be reduced to 64 kg/m.

Next, it was found from analysis of data on many transit systems that transit vehicle cost per unit of capacity is not noticeably dependent on capacity, which led to the conclusion that, for a given number of riders, the size of the fleet, and hence its cost, will be minimum if the average speed is a maximum. The highest average speed requires that there be no intermediate stops, which is possible with small vehicles and off-line stations. Similar analysis of operating and maintenance (O&M) costs shows that O&M cost per unit of capacity per unit of distance is markedly independent of vehicle size, which led to the conclusion that the O&M cost per year is inversely proportional to daily average load factor. Study of daily average load factors in various systems showed a marked increase if the service is demand-responsive rather than scheduled. But demand-responsive service is exactly what is provided if the stations are off-line, because vehicles can wait to provide service, like taxis, rather than having the passengers wait for the vehicles. The exact factors that fundamentally minimize the cost of a transit system also provide the best service.

For these reasons the concept of PRT will become a common form of public transportation once it is understood how such a system can provide safe, secure, dependable, and adequate-capacity service at minimum cost. In this paper, following a description of Taxi 2000, which Anderson (1988) and his colleagues developed, the factors involved in design for maximum safety with adequate capacity are discussed.

Description of the Taxi 2000 PRT System

Performance Goals

The fundamental goal of the Taxi 2000 program has been to design a PRT system that will not be unnecessarily limited in capacity, speed or ability to grow indefinitely. Safety and dependability cannot be compromised in meeting the goal. Anderson (1992)
showed that these qualities are achievable in a system of many small vehicles. Planning studies have shown that early PRT systems will need a headway capability in the range of two to four seconds, but that as the system grows, a headway capability down to a range of one-half second is desirable. Much work, summarized below, has convinced us that half-second headway will also be practical, but that it requires very careful attention to all matters of safety. As to speed, the current system is designed for 13.4 m/sec, but the guideway and propulsion system have been designed so that speeds up to the range of 20 m/sec should be practical.

To enable the system to grow indefinitely without severe limits on computer power, the Taxi 2000 control system uses a hierarchy of computers — on the vehicles, at wayside, and in a central location — that permit the design of standard software and hardware elements that can be repeated for each vehicle and each zone of the guideway. The central computer performs only supervisory functions. The basic philosophy of design of such a control system was described during the 1970s by several authors of papers in the Proceedings of the Third International Conference on PRT, Gary (1976).

Development Status

The design of Taxi 2000 followed over a decade of study, analysis, planning, observation of the work of hundreds of engineers, and listening to comments of many people interested in public transportation. Currently, the study phase for the Chicago RTA has been completed and the Taxi 2000 Corporation (fax 617-246-9877) is ready, with a multidisciplinary industrial team, to undertake a 33-month hardware development phase leading to proof of performance and cost on an 800-meter oval test track. The demonstration phase will be a network of about 4000 meters of one-way guideway with about ten stations in a Chicago suburb. Operation is expected in 1996.

The Switch

Because a fully developed PRT system has many switches, two per station and others for line-to-line merges and diverges, an adequate switch design is the most fundamental element in the development of a successful PRT system. The two initial tradeoffs are between an in-track switch and an in-vehicle switch. From the viewpoint of safety, with in-track switching there must be enough time headway between vehicles so that 1) the switch can be thrown from the opposite position, 2) its position can be assured to be locked in the correct position and verified, and 3) the vehicle can be stopped well before hitting the switch if verification does not occur. The time headway that must be allowed for stopping is approximately the line speed divided by the braking acceleration. This number, in practical cases, is large enough by itself to severely limit the safe time headway. Estimates vary in detail but a minimum headway in the range of 8 to 12 seconds would appear to be near the limit. With in-vehicle switching, there is no such limit.
An in-vehicle switch could be electromagnetic or mechanical. For reasons of safety, electromagnetic switches have required a mechanical backup, which if it meets all criteria may as well be the primary switch, unless it is shown that the life-cycle cost of an electromagnetic-mechanical combination would be lower. At present, the Taxi 2000 switch is mechanical. It is very conservatively designed and cannot disengage in a diverging section of guideway. Such a switch must also be designed 1) so that it is bistable, 2) so that there is no position in which it can impale on any track part, 3) so that it is naturally held in position during the switching maneuver, and 4) so that maintenance personnel could move the switch manually in an emergency. These criteria led to a switch consisting of wheeled arms rotating about a longitudinal axis and configured so that the line of force of the engaged switch passes through the center of the support bearing. Switch rails in the guideway are flared at both ends to permit smooth engagement and disengagement in presence of side winds.

The Guideway

Guideway design is constrained mainly by the requirements of switching, ride-comfort, and cost. After the switch tradeoff was made, the next key tradeoff was the location of the vehicle with respect to the guideway. Designs have been developed for top-mounted, side-mounted, and bottom-mounted vehicles. Provided that we could solve the problems of winter weather, we found seven reasons to prefer top-mounted vehicles, the most important of which relate to the post and foundation size, the natural frequency in bending and torsion, and the ease of switching.

Interwoven in the decision process was also the tradeoff of suspension type: wheels, air, or magnetic fields. While magnetic suspension has well-advertized advantages at very high speeds, these advantages disappear at urban speeds when compared with rubber-tired wheels. Air suspension requires too much area, while the criteria of economy and visual impact dictate a minimum cross section. We concluded that the vehicle should be supported on wheels, and, considering the requirements of switching and cost minimization, concluded with Irving and his colleagues (1978) that the guideway should be a U-shaped configuration as narrow as practical with a vertically oriented chassis inside, and the passenger cabin on top. Polyurethane wheels provide lateral support.

The Taxi 2000 guideway is a truss structure fabricated to ordinary structural tolerances. To obtain adequate stiffness in torsion and bending, each truss is bolted firmly to a specially-designed moment-carrying bracket at the top of a post, and the joint, required for thermal expansion, is close to the point of zero bending moment in a clamped beam. Overlap angles provide continuity while allowing for thermal expansion. The running surfaces are adjustable with respect to the truss with the joint overlapping the guideway joint enough so that any slope discontinuity is eliminated even if a post should settle. The guideway is covered for four reasons: to provide protection against ice and snow, to provide electromagnetic shielding, to reduce lateral drag force due to wind, and to provide an external appearance independent of structural characteristics.
Propulsion and Braking

To achieve high capacity safely, it is shown below that propulsion and braking should be provided through linear electric motors. There are two basic types: synchronous and induction. While linear synchronous motors have higher efficiency, they require track segmentation, which raises the complexity and cost of the guideway. Today, linear induction motors (LIMs) can be driven from amply small variable-frequency electronic drives. By selecting the frequency at each speed to minimizes current, the efficiency is in the range of 60 percent and the motors provide braking right to a stop.

Each vehicle has a pair of LIMs mounted on a separate bogie at the bottom of the chassis with the reaction surfaces horizontal. The LIM bogie is supported from the running surfaces by stiff polyurethane tires and connected to the chassis through horizontal linkages that permit vertical movement of the vehicle due to weight variation without affecting the LIM gap. A friction parking brake is provided to hold the vehicle’s position when at rest in a station, and for emergencies.

The motors receive power from 600-volt DC power rails through sliding contacts. To provide continuity of service during power interruptions, either wayside battery banks or motor-generator sets, or both can be provided. Use of wayside batteries permits the system to avoid drawing utility power during peak-use periods, and we have found that such use of batteries is often quite economical.

The Vehicle

The vehicle configuration followed directly once the switch and guideway were determined. It has a vertically oriented chassis inside the guideway with the passenger cabin firmly attached at the top. With three-abreast seating and all passengers seated, all requirements for safety are met. A wheelchaired person and one attendant are accommodated. The vehicle body will be an aluminum frame with composite panels forming the exterior and interior surfaces. Heating and air conditioning will be provided, with the mechanical components in the chassis. For reasons of safety, the electric power provided in the cabin is at 24 volts only.

The Control System

The control system operates on the quasisynchronous principal as opposed to the synchronous or asynchronous principles (see Irving (1978)). This choice provides the highest practical throughput with the least complexity of the central controller and minimizes the station wait time. Redundant, fault-tolerant microprocessors aboard the vehicles permit maneuvering within ride-comfort and power limits with only a speed signal provided from wayside, throw the switch based on a wayside command, monitor various functions for failures, perform a predetermined action if a specific failure occurs, provide two-way communication with the passengers, and operate the door lock,
parking brake, and other secondary functions.

Redundant, fault-tolerant wayside computers, located in station buildings perform two functions: zone control and station control. Zone control provides the speed signal to the vehicles in its zone through a lossy coax cable, watches for and reacts to anomalous behavior, reduces the speed to a safe value when necessary, and provides switch commands. At a predetermined point in advance of each diverge section of guideway, the zone controller (ZC) interrogates each vehicle for its destination. The ZC, containing the switch command for every station, looks up the appropriate command and transmits it to the vehicle. By linking the ZCs to the central computer through fiber-optic lines, the switch commands will be revised based on traffic conditions, thus providing dynamic rerouting to specific detail not possible with automobile traffic. Each station controller commands and monitors all actions involving passenger flow in its station. Commands to vehicles are transmitted through the ZC.

A redundant pair of fault-tolerant central computers provide optimum rerouting of empty vehicles, adjust the line speed for weather conditions, monitor the flow into stations and at merge points to either delay passengers in stations or reroute traffic as needed, compute system dependability (Anderson (1992)), and gather data on system operations. It is common to suppose that the software requirements for such a system are immense, but careful study has shown that they are quite modest.

Principles of Safe and High-Capacity Design in PRT

Minimize the Probability and Consequences of Failures

1. Minimize the number of moving parts. The Taxi 2000 vehicle has four main support wheels, eight lateral stabilization wheels, four switch wheels, an four LIM-bogie wheels. The LIM propulsion and braking system has no moving parts. The only other moving parts are the switch arm, the parking brake and the doors.

2. Minimize the stress on all parts, particularly on the moving parts. Because of the small size of a PRT vehicle, there is little cost penalty in over-design of tires, bearings, axles and other components to keep the stresses in the range in which the chances of wheel, axle or bearing failure is virtually nil. The principle of the proportionality of stress to size has been known since first stated by Galileo.

3. Minimize the opportunity for unusual forces on the vehicles. Taxi 2000 vehicles ride on smooth tires on smooth steel surfaces in a protected, well ventilated guideway away from the heat and ultra-violet radiation of the sun, away from ice formation on critical parts, away from opportunities for debris to land on the running surfaces, and away from broken road surfaces.
4. Minimize the effects of severe weather. The wheels that support Taxi 2000 vehicles run inside of a U-shaped guideway covered on the sides and top except for a 150-mm slot through which the chassis passes. The bottom is open to permit rain, snow and ice to fall through. With this design, relatively little snow and ice can interfere with operations and that small amount is easily removed from critical surfaces. By careful shaping of the covers, the lateral wind force is reduced by a factor of about two.

5. Minimize thermal stresses due to day-night and seasonal temperature variations. The expansion joints described above virtually eliminate thermal stresses.

6. Minimize the possibility of overheating in the electrical systems. Electric currents and critical temperatures are monitored continuously with appropriate responses programmed into the computers. Careful attention to heat transfer from the LIMs and drives provide further protection.

7. Use fault tolerance and managed redundancy where possible to minimize the consequences of failures. All computer systems in Taxi 2000 have these features. Ticket machines in the stations are duplicated.

8. Minimize the chance and consequence of fire aboard a vehicle. No high-voltage equipment is placed in the vehicle body. All construction is of noncombustible material. Temperatures at critical points are monitored and currents are shut off if the temperature exceeds a specified limit. Vehicles are cleaned as frequently as needed to remove debris left by passengers.

9. Minimize the probability of damage due to vandalism. Because of the narrow slot on top of the guideway, not only is ice and snow kept out, but, because the slot is over five meters above ground, it is very difficult to inject an object large enough to do any damage. Object and ice deflectors in front of the wheels will keep small objects from harming the vehicles. Stations will be clean, well lit, and monitored by standard television-monitoring systems. Infrared sensors are used to warn operators of the presence of people during the night.

10. Minimize the possibility of externally induced failure. In places in which it is likely that a truck may hit a support post, the usual procedure will be to place a highway barrier around it, yet the guideway and post design has taken into account the possibility of a post being knocked out.

Time Headway and the Linear Induction Motor

The linear induction motor is a key component of a safe, high-capacity PRT system. The basic argument relates to the time headway achievable safely and dependably, and how the minimum safe headway depends on selection of certain components. Several papers on this subject are included in Anderson (1974).
The argument can be seen from the equation for minimum time headway, equation (1).

\[ T_{\text{min}} = \frac{L}{V} + t_e + k \left( \frac{V}{2} \left( \frac{1}{a_e} - \frac{1}{a_f} \right) \right) \]  

The first term is the time required for a vehicle of length \( L \) travelling at a velocity \( V \) to travel one vehicle length. It is the minimum possible headway. The second term \( t_e \) is the time required to detect the malfunction and apply the brakes. The third term is the available stopping distance after the brakes are fully applied divided by the cruising speed \( V \). \( a_e \) is the emergency braking rate and \( a_f \) is the failure braking rate. \( k \geq 1 \) is a dimensionless number included to increase safety.

To appreciate the fundamentals of the question of minimum headway, consider some numerical values. For the Taxi 2000 vehicle, \( L = 3 \) m and \( V = 13.4 \) m/s. Therefore

\[ \frac{L}{V} = 0.224 \text{ sec.} \]

Consider \( t_e \). It is the sum of 1) the time between failure occurrence and braking initiation, and 2) the time required to fully apply the brakes. In an automobile, the time to react to an emergency depends on human reaction time. Under automation, the time to begin applying the brakes depends on the characteristics of the control system. In a PRT system designed for maximum throughput, it is necessary for the zone controller to sense the position of each vehicle at frequent intervals. In the current design of the Taxi 2000 control system, each vehicle’s state is interrogated every 100 msec. The first part of \( t_e \) is then 0.1 sec plus the much smaller time for the computer to react. The second part of \( t_e \) must be as short as practical with current technology. With electromagnetic braking, this time is the inductive time constant of the motor, which is of the order of 10 msec. For an up-to-date PRT system, we therefore estimate

\[ t_e = 0.12 \text{ sec.} \]

Consider the third term in equation (1). From this term, the value of linear electromagnetic braking becomes more apparent. The term \( a_e \) must be as high as practical. If all passengers are seated, simple experiments show that a 0.5g deceleration will not throw a passenger out of the seat. If passengers are standing, even half this acceleration is too much, so one of the requirements of PRT safety is that the vehicle be designed for all passengers seated. If braking is through wheels, \( a_e \) depends on the coefficient of friction. It is necessary to assume the worst conditions. These would be a wet or snowy day in which the vehicle is going downhill in a tail wind. Moreover, it must be assumed that the vehicle ahead may fail by locking its brakes on a dry section of guideway. Friction braking tends to be constant-force braking rather than constant-deceleration braking, but to minimize the length of off-line guideway, it is necessary that braking deceleration be controlled. With LIMs used for braking, these
requirements are readily satisfied since LIMs provide braking independent of friction, whereas with braking through wheels they are not.

The value of $a_f$ used in equation (1) should be the maximum that can conceivably occur. With wheel braking, it must be assumed that the brakes could suddenly lock while the vehicle is on dry pavement. There must be sufficient tread on the tires and the running surface must be sufficiently rough to make the coefficient of friction as high as practical. In this case $a_f = 0.9g$. If the vehicle is propelled by linear induction motors, it can also be braked by the same devices and both the tires and the running surface can be smooth, which results in lower tire noise and less tire wear. A locked bearing, however rare, then cannot cause the vehicle to stop as fast as $a_s$, in which case the sum

$$t_e + k\frac{V(1 - \frac{1}{a_s})}{2(a_s - a_f)}$$

can become negative.

It is necessary to look for all other ways a vehicle can stop quickly and to assess their probability. The diverge section of the guideway must be examined carefully. If the in-vehicle switch were to disengage, the vehicle could impale on the diverge junction. Prevention requires that the designer insure that the switch cannot disengage and that it is sufficiently strong so that it will not break under the most extreme conditions.

Control

The Taxi 2000 control system, which is designed with safety as the first priority, is described above. The critical maneuvers that such a system must perform repeatedly and flawlessly every day of the year are

- Merging from a station into main-line traffic;
- Merging of traffic on two main lines; and
- Deceleration into a station.

The elements of control-system design for safe operation are:

- Simplicity in software architecture so that software is as easy as possible to write and check. Separate functions have been listed above, the software for each of which must be programmed and checked using the latest protocols for development of reliable operational software, such as discussed by Shulmeyer (1990).

- Use of checked and managed redundancy in critical functions. Today, fault-tolerant computers are commercially available for a variety of critical applications in which a failure of a computer could produce serious consequences. These computers have built in tests and alternative paths in case of failure. A pair of fault-tolerant
computers should be used aboard each vehicle with one as a hot standby, arranged to
take over if the other fails. Computers used for zone control, station control and
central control should be similarly configured. Speed and position sensors should be
redundant. In Taxi 2000 there is a pair of LIMs and variable-frequency drives, either
of which can keep the vehicle moving according to commands except under reduced
speed in the most extreme conditions such as high wind or grade.

- Clearly defined failure-management strategies. Every possible failure must
be considered and a strategy developed for reacting to it in a fail-safe manner. For
example, in Taxi 2000 each vehicle’s control system is configured so that the lack of
an active speed signal from wayside at each check interval (100 msec in Taxi 2000)
produces a command to slow to a predetermined default speed if the speed signal is not
received. In switch operation, in Taxi 2000 each command to throw the switch is
accompanied by a command to lock out the wayside speed signal a switch throw time
(0.5 sec in Taxi 2000) later unless a signal is received from a proximity sensor
positioned to determine the position of the switch. Thus, the vehicle will automatically
decelerate to the default speed if the switch signal is not received.

Ultimate Passenger Protection

Every precaution must be taken in design of the control system to prevent collisions,
but in no transportation system can it be assumed that no collision could ever occur.
The prudent path is to design to minimize the consequences. If all passengers are
seated, it is possible to protect them if there should be a collision. With all passengers
seated, the design goal for PRT can and should be that no system failure can cause
passenger injury. The problem is simpler than in protection of automobile passengers
because there can be no head-on collisions, direct side collisions, or roll-overs, because
the vehicles are of uniform size and mass with bumpers at the same location, because
the speeds are closely controlled by the system, and because more adequate bumpers
can be used than common in automobiles. Garrard, Caudill and Rushfeldt (1976)
studied how to design PRT vehicles so that the passengers are protected in a collision.

Injury prevention in a collision requires the right combination of three lengths: the
length of a shock-absorbing bumper, the throw distance between the passenger and a
padded surface, and the deflection of the padded surface. An air bag functions as a
means to substantially reduce the throw distance and to increase the deflection of a
padded surface, both of which reduce the probability of injury. Passenger protection
also requires that the vehicle structure not intrude into the passenger compartment
during a collision, which of course is more of a problem in high-speed collisions.

The kinetic energy that must be absorbed during the collision between two similar
vehicles is half the kinetic energy of one of the vehicles. If the stroke of a shock-
absorbing bumper is \( S \), the deceleration during collision is \( a \), and the relative speed
is \( V_c \), then, equating the kinetic energy to the work of the shock absorber.
\[ \frac{mV_c^2}{4} = maS \quad \text{or} \quad V_c = 2\sqrt{aS}. \]

Reasonable values of \( S \) and \( a \) are 0.1\( m \) and 10g, respectively, which gives \( V_c = 6.26 \text{ m/s} \). It was found that a hydraulic shock absorber with a 0.1\( m \) stroke and an energy-absorption rating suitable for a vehicle of the mass of a reasonably designed PRT vehicle was commercially available at a mass of only 13 kg; however, as the vehicle mass increases, the size of such a shock absorber quickly becomes prohibitive, which means that the shock absorber must be longer or the collision energy must be absorbed in crushing the vehicle.

With a throw distance similar to the distance of the occupant of an automobile to a padded dashboard, Garrard and his colleagues found that it is relatively simple to protect passengers if \( V_c \leq 7.5 \text{ m/sec} \) and that careful attention to collision-energy management in a crushing vehicle body plus the use of an air bag can assure protection at \( V_c \leq 15 \text{ m/sec} \).

**Station Features**

Safety in PRT stations involves protection against falling off the station platform, being hit by a vehicle, and assault. The problem of falling off the platform is no different than in conventional transit and can be protected against by suitable barriers. While most conventional transit systems have open platforms, automatic doors can be placed in front of each boarding position, but of course with the penalty of lower reliability and greater cost. Warning sounds may be sufficient. The problem of assault is most often mentioned. PRT systems should have television monitors with infrared devices to warn monitoring personnel of a person in the station in non-busy periods. Experience at the Morgantown, West Virginia PRT System showed that the existence of such devices markedly reduces perverse incidences. The station areas must be well lit and must be designed to have no corners where an assailant can hid.

**Conclusions**

Careful attention to the design of all elements of a PRT system can result in a level of safety perhaps higher than can be attaine in large-vehicle transit systems. This conclusion is counterintuitive to many transit professionals and requires proof through extensive testing and demonstration, the success of which can bring marked cost reductions and service improvements in public transportation. Recent advances in computer hardware and software make the difference from the 1970s. The PRT designer will have to demonstrate that he has not overlooked safety as a primary requirement in any portion of his design.
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DEVELOPMENT OF THE DLPU, AN AIRBORNE UNIT FOR DATA LINK EXPERIMENTS

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ABSTRACT

The purpose of this paper is to present experience gained at the National Aerospace Laboratory NLR with the development and certification of digital computer systems for application in civil aviation. The safety requirements that digital avionics systems should meet are laid down in JAR-25. An equipment manufacturer can obtain a certificate of approval from the civil aviation authorities by demonstrating compliance with a mutually agreed basis for certification. RTCA document DO-160 specifies tests, that systems may be subjected to for demonstrating suitability of the hardware to operate in airborne environments. For software development, verification and validation, the guidelines given in RTCA document DO-178 need to be followed.

By developing a Data Link Processor Unit (DLPU), NLR gained experience with the certification of digital avionics systems. NLR has all the facilities available for executing the environmental tests according RTCA DO-160. The NLR procedures for development of information systems require little adaptation to comply with RTCA DO-178. In the overall certification process, little attention is given to the hardware development itself, but the NLR procedures for the development of information systems are applicable to hardware development as well.

1. INTRODUCTION

Within Europe, air traffic control (ATC) is operating near maximum capacity. The introduction of data link allows air-ground machine-machine communication. This enables ATC automation, which is essential to reduce controller workload and increase air space capacity.

Eurocontrol, the organization in Europe for the safety of air navigation, is currently undertaking a programme for developing the basic elements of an SSR Mode S aircraft surveillance system and to provide an experimental infrastructure. The Mode S system supports a moderate capacity, reliable two-way air-ground digital data link [ICAO 1988]. A

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1 SSR Mode S (Secondary Surveillance Radar Mode Select) is a surveillance and communication system for air traffic control. It employs ground based interrogators and airborne transponders. A principal feature of Mode S is that each aircraft is assigned a unique address code. Using this code, interrogations can be directed to a particular aircraft and replies unambiguously identified. Surveillance is accomplished by use of 56-bit transmissions in both directions. In these transmissions, the aircraft reports its altitude, identity, etc.. Data link messages of 56 bits can be included with the surveillance messages. Longer data link messages of up to 16 segments of 80 bits can be transmitted instead of the surveillance messages [ARINC 1989a].
Data Link Processor Unit (DLPU) is required to interface the Mode S equipment on-board of the aircraft with other avionics systems.

In December 1987 NLR was commissioned by Eurocontrol to develop a prototype DLPU and subsequently produce twelve identical units. Since the DLPU was to be installed in commercial aircraft, certification by the civil aviation authorities was mandatory. In the Netherlands, certification is supervised by the Rijksluchtvaartdienst (RLD). The civil aviation authorities of France (STNA) and the United Kingdom (CAA) were also involved in the certification, because the DLPU was initially to be installed in aircraft of French and British airliners. Figure 1 shows a picture of the DLPU with the top cover removed.

The purpose of this paper is to present experience gained at the National Aerospace Laboratory NLR with the development and certification of digital computer systems for application in civil aviation. The development of the DLPU will be used as an example to show measures taken for assuring safe application in civil aircraft.

First a general overview will be given of the certification of digital avionics systems. Existing requirements and procedures for the safety assessment at system level as well as for hardware and software will be presented briefly.

2. CERTIFICATION OF DIGITAL AVIONICS SYSTEMS

For Europe, the safety requirements that avionics systems on-board transport category civil aircraft should meet are laid down by the Joint Airworthiness Authorities (JAA) in JAR-25 [JAA 1989]. For digital avionics systems, the most important regulation is paragraph 25.1309: "Equipment, systems and installations". According to this paragraph, digital avionics systems must be designed so that:

(a) they perform their intended functions under any foreseeable conditions,

(b.1) the occurrence of any failure condition which could prevent the continued safe flight and landing of the aeroplane is extremely improbable and

(b.2) the occurrence of any other failure condition which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions is improbable.

To provide interpretations and acceptable methods for meeting the regulations, AMJs (Advisory Material - Joint) are issued. AMJ 25.1309
quantifies items b above, by specifying an inverse relationship between the probability of occurrence of a failure and the effect of a failure (see figure 2).

An equipment manufacturer can obtain a certificate of approval from the civil aviation authorities by demonstrating compliance with a mutually agreed basis for certification. System safety assessment (SSA) is normally the method used for demonstrating compliance with JAR 25.1309.

2.1 System safety assessment
First a preliminary hazard analysis (PHA) is performed to identify safety critical areas. Then the system is classified into one of the three criticality categories: critical, essential and non-essential.

- Critical systems are those for which a failure condition or design error would prevent the continued safe flight and landing of the aircraft.
- Essential systems are those for which a failure condition or design error could reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions.
- Non-essential systems are those for which failure conditions or design errors could not significantly degrade aircraft capability or crew ability.

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2 A hazard is a state or condition of a system that, combined with certain environmental conditions, could lead to an accident [Leveson 1986].
2.2 Hardware safety assessment

The hardware safety assessment activities depend on the criticality category of the system. A Failure Mode Effect and Criticality Analysis (FMECA) should be performed on any critical or essential system. For critical systems it may be necessary to provide further quantitative analyses, such as Fault Tree Analysis (FTA) and probability analysis, in case the system differs from existing systems with respect to for instance technology and complexity. For non-essential systems it is necessary to establish that a failure will not contribute to a failure of a critical or essential system [Spitzer 1987]. Fault isolation and containment techniques may be used to achieve this.

Avionics systems are required to operate reliably and safely in the environmental conditions found in aircraft. RTCA document DO-160 (EUROCAE ED-14): "Environmental Conditions and Test Procedures for Airborne Equipment" describes nineteen test sets that avionics equipment can be subjected to for determining their acceptability for operation in civil aircraft. The current revision of DO-160 is C [RTCA 1990]. For each test, DO-160 describes the purpose of the test, the test equipment and the test procedures. A list of the tests follows:

- temperature and altitude
- humidity
- vibration
- water proofness
- salt spray resistance
- power input
- audio frequency conducted susceptibility
- radio frequency susceptibility
- lightning induced transient susceptibility
- temperature variation
- shock
- explosion proofness
- fluids susceptibility
- fungus resistance
- magnetic effect
- voltage spike conducted
- induced signal susceptibility
- radio frequency emission and
- induced voltage
- shock and vibration
- fluid susceptibility
- fungus resistance
- magnetic effect
- voltage spike conducted
- induced signal susceptibility
- radio frequency emission and
- induced voltage

For most of these test sets, different categories are defined, which are associated with different environments that can be found in civil aircraft. The selected categories depend on the type of aircraft and the location inside the aircraft where the equipment will be installed.

2.3 Software safety assessment

Currently there are no methods to quantify the probability of the residual software errors within a system with sufficient confidence to form a total system safety analysis [Perry 1988]. AMJ 25.1309 supports this view and refers to RTCA document DO-178 (EUROCAE ED-12) as a
method to establish confidence in the quality of the software. This paper addresses revision A of DO-178 [RTCA 1985] (which is currently being rewritten). The purpose of DO-178 is to describe techniques and methods that may be used for the orderly development and management of software for airborne digital computer-based equipment and systems. The application of these techniques and methods will result in documented software that is traceable, testable and maintainable.

DO-178A distinguishes three levels of software, i.e. Level 1, 2 and 3. The level required for certification is based on the criticality classification of the system (see section 2.1). In principle, Level 1 is required for critical systems, Level 2 for essential systems and Level 3 for non-essential systems (a lower level than associated with the criticality classification of the system is however not excluded). The software level has impact on the required amount of verification, validation and documentation.

DO-178A gives guidelines for:
- software development, verification and validation,
- software configuration management and quality assurance disciplines and
- documentation.

Software development, verification and validation
DO-178A divides the generation and delivery of software into three phases: development, verification and assurance. Figure 3 shows the various activities in the development and verification phases. The top row shows the development activities and the bottom row the related verification activities. The products of the development and verification activities, i.e. documents and code are in the centre row.

Assurance is the method used to demonstrate to the civil aviation authorities compliance with the development and verification process appropriate to the software level. For Level 1 software the results of the verification process must be recorded and retained. All problems resulting from the verification process should be logged and corrective action tracked. Traceability matrices that relate a requirement to a higher level requirement must be developed. An audit should be performed to assess the completion of tasks. For Level 2 software a summary of the verification process is required together with a Statement of Compliance. All problems resulting from the verification process should be logged and corrective action tracked. Level 3 software requires no assurance measures.

Software configuration management and quality assurance disciplines
Besides the use of formal verification steps after each software development activity, DO-178A prescribes that the disciplines of Software Configuration Management (SCM) and Software Quality Assurance (SQA) are applied during software development.

SCM sets the standards for software identification, change control and status reporting throughout the life of the software. Its main aim is
Fig. 3 Software development and verification activities

to ensure that changes in the software are implemented in a disciplined, controlled way.

SQA involves the use of quality audits and other means to ensure the integrity of the products, the corresponding documentation and the management process. It consists of the policies and procedures (e.g., error reporting) necessary to ensure that the software meets the quality standards imposed on its development.

**Documentation**

Documentation is an essential part of every software development project, although no goal in itself. DO-178A specifies 14 documents in a complete set of software documentation. Most documents would be expected in a decent development process. The document titles and their requirement for certification (software level dependent) are listed in Table 1.

3. DEVELOPMENT OF THE DATA LINK PROCESSOR UNIT

In January 1988, the development of the DLPU started and the prototype unit was completed in March 1989. The delivery of the 12 production units took place between October and December 1989 and the certificate of approval was obtained in September 1990. Since then, units have been installed in aircrafts of commercial airliners. Initial data link validation experiments have been started recently, by a.o. the civil aviation authorities of France and the United Kingdom.

In January 1992 NLR was awarded a follow-on contract for upgrading the DLPU software. This contract involves the incorporation of new applications and enhancing existing applications and interface protocols.
The upgrade of the DLPU software, including its re-certification is expected to be completed in March 1993.

3.1 The Mode S data link system
The basic components of a Mode S air-ground data link system are shown in the simplified block diagram of figure 4. Ground elements are the Mode S interrogator and the Ground Data Link Processor (GDLP). Aircraft elements are the Mode S transponder and the Data Link Processor Unit (DLPU).

![Fig. 4 Mode S air-ground data link system](image)

The Mode S interrogator provides ground modulator/demodulator (modem) functionality for the Mode S data link. The Mode S transponder provides the aircraft modem function.

The GDLP functions include the segmenting and/or reassembly of messages for transfer over the Mode S data link, as well as providing Mode S data link management. The DLPU performs message processing functions equivalent to those of the GDLP. Additionally, the current DLPU implementation, provides support for a number of data link applications. One application is the exchange of Air Traffic Control (ATC) messages between pilot and Air Traffic Controller. Another application is the transfer of weather information from ground-based databases to a cockpit printer, upon pilot's request.

3.2 System safety assessment
In the PHA of the DLPU it was established that in case of a failure, no significant degradation of aircraft or crew ability will appear. The criticality category was therefore classified as "Non-essential". The software level associated with this category is Level 3.

### Table 1 DO-178A documentation

<table>
<thead>
<tr>
<th>DOCUMENT TITLE</th>
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<tbody>
<tr>
<td>configuration index</td>
<td>R</td>
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<td>software requirements</td>
<td>A</td>
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<td>design description</td>
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<td>programmer's manual</td>
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<td>executable object code</td>
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<td>support/development system configuration</td>
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<td>accomplishment summary</td>
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<td>test plan, procedures and results</td>
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<td>design standards</td>
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<td>system requirements</td>
<td>A</td>
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<tr>
<td>plan for SW aspects of certification</td>
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</table>

* "A" for post-modification re-certification

**NOTES:**
1. "R" signifies documents required to be made available to the regulatory agency as applicant's records. "A" signifies documents which are available to support a particular certification plan.

2. When neither R or A is indicated, the document should not be needed for certification approval.
The FMECA conducted during the later stages of the design [Manders et al. 1990] showed that only failures of the interfaces with the aircraft systems, i.e. the ARINC 429\textsuperscript{6} data buses and the power input, could result in active failures. The electrical circuits associated with the interfaces were analyzed and their failure rates established, using the parts-count method. The failure rates per hour are:

- for an ARINC 429 input: $0.32389 \times 10^{-6}$
- for an ARINC 429 output: $0.16676 \times 10^{-6}$
- for the power input: $1.02660 \times 10^{-6}$

Since the actual interconnection of the DLPU with other avionics systems is aircraft dependent, it was not possible to establish criticality classifications for the effects of DLPU interface failures. A separate certification activity is therefore required for each DLPU installation. First the criticality classification of the effects of failures in the DLPU interfaces need to be established. Then, using the failure rates quoted above, failure probabilities per flight hour can be calculated. These probabilities should satisfy the severity of effect versus probability relationship shown in figure 2.

### 3.3 Hardware development

The modular design of the DLPU hardware is depicted in figure 5 [Wedzinga 1990]. A high speed system bus interconnects four electronic cards, i.e.:

- one Application processor card\textsuperscript{7},
- one Battery back-up memory card\textsuperscript{8} and
- two identical ARINC interface cards\textsuperscript{9}.

The Application processor card executes the Mode S data link functions and applications. The Battery back-up memory card is used to store configuration data tables and logged error messages. The ARINC interface cards provide interfaces to the connected avionics systems on the basis of ARINC 429 data buses. The processor on each ARINC interface card executes communication protocols.

The size of each card is 160 mm x 233 mm. The system components, i.e. cards, power supply, interconnection bus, etc. are mounted in a housing with a size of 194 mm x 124 mm x 374 mm (height x width x

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\textsuperscript{6} ARINC 429 is a specification for a digital data bus for use in civil aircraft. It is a unidirectional bus with only one transmitter, but multiple receivers (max. 20). Data is transmitted in 32 bit words separated by a minimum of four bit times. Words are subdivided into fields, including an 8 bit label, which identifies the data, up to 21 bits of data and an odd parity bit. The electrical waveform is bipolar return-to-zero and transmission rates are 12-14.5 kHz or 100 kHz [ARINC 1989b].

\textsuperscript{7} Radstone PMV68 CPU-1; CPU: 68020, 12.5 MHz; SRAM: 512 kB; EPROM: 512 kB, RS-423: 2.

\textsuperscript{8} MRL design; SRAM: 32 kB (battery back-up); Real-time clock (battery back-up); Watch-dog timer; 1-60 s; Discrete inputs: 16; Discrete outputs: 8 (max.).

\textsuperscript{9} MRL design; CPU: 68000, 10 MHz; SRAM: 64 kB (local) + 64 kB (dual ported); EPROM: 128 kB; ARINC 429 in: 8; ARINC 429 out: 4.
The DLPU will be installed in a controlled temperature location (-15 to +55 °C). Furthermore, the unit has to be able to operate in experimental aircraft without forced aircooling. Analysis revealed that temperatures up to 85 °C could be expected within the unit. Since there was not enough space inside the unit to fit cooling equipment, it was decided to use conduction cooling and extended temperature range (-55 to +125 °C) components on all the cards. In order to reduce power consumption, low power components were used whenever possible. A further reduction in power consumption was obtained by using active terminators on the system interconnection bus.

Convection openings were introduced in top and bottom covers (also used for forced air cooling) and measures were taken to obstruct the natural convection within the unit as little as possible. To improve convection from the housing to ambient, vertical slots were shaved out from the side panels and the power supply panel (front) was furnished with cooling fins.

Shock/vibration
Stiffness of the cards was improved by applying a central stiffening bar, a top stiffening bar (also used as front panel and extractor) and wedgelocks on the sides (also used to fix the cards and provide thermal conduction).

The design of the housing is based on the proven concept of previously designed housings. All panels are made from an aluminium alloy.

Electromagnetic interference (EMI)
All panels of the housing are joined electrically. This "cage of Faraday" reduces radiated emission and susceptibility for induced signals.

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10 Conduction cooling is achieved by a thermal frame (aluminium alloy) hot bonded onto the printed circuit board. The thermal frame transfers the heat generated by the components to both sides of the card, which are clamped in the chassis wall by screw-driven wedgelocks.
NLR has all the facilities required to perform environmental tests according DO-160. The DLPU hardware was subjected to the following environmental tests:

- temperature and altitude: Cat. A1
- temperature variation: Cat. C
- humidity: Cat. A
- shock: Conform figure 7.2 of DO-160B
- vibration: Cat. A
- magnetic effect: Cat. E
- power input: Cat. B
- voltage spike conducted: Cat. E
- audio frequency conducted susceptibility: Cat. Z
- induced signal susceptibility: Cat. Z
- radio frequency susceptibility: Cat. Z
- radio frequency emission: Cat. Z/Cat. B

See Appendix A for more details about these environmental specifications.

3.4 Software development
This section pertains to the software development under the current software upgrade contract.

The software of the DLPU [Aupers et al. 1992] has a modular design. Its architecture is depicted in figure 6. In principle, the software is written in the language 'C'; Assembly language is used only where necessary for performance reasons. On all processor cards, the software consists of independent tasks scheduled by the real-time kernel pSOS\(^*\). Tasks (on one processor card) can communicate using services provided by pSOS\(^*\), such as message queues, events and semaphores. Device drivers perform the communication between tasks executed by the Application processor card and Protocol handlers executed by the ARINC interface cards.

In principle, the software development takes place according to the procedures of the NLR Informatics division [NLR-I 1990]. Where necessary adaptations are made in order to conform with DO-178A.

Development activities
The software development process according to NLR procedures is very similar to DO-178A. The main difference can be found in the Design activity (D2 in figure 2). At NLR this activity is split up into Technical concept and Detailed design. In the Technical concept phase, a software architecture is established, consisting of the division into software modules and the

\(^*\) pSOS is a trademark of Software Components Group.
specification of the interfaces between the modules. In the Detailed
design phase, the technical specification for each module is written.

**Verification activities**
The Software requirements and the Technical concept are reviewed by
Eurocontrol. Two persons are assigned to each software module; one
produces the detailed design, whereas the other implements the module
code. The engineer responsible for coding the module first performs
the review of the module design. The module designer in turn performs
the code walk through after the module coding. Module testing is
executed by the implementor of the module.

**Assurance activities**
Although formally no assurance is required for Level 3 software, it
was decided to produce and retain reports of all reviews.

**Software configuration management and software quality assurance**
SCM procedures have been established for a.o. the numbering of docum­
ments, configuration control and code and media control. SQA activities
have been defined, such as: audits and non-conformance reporting.

**Documentation**
NLR standard documentation covers most of the documents required by
DO-178A for Level 1 software (see table 1). Documents that need to be
written especially for certification approval are: Plan for software
aspects of certification (Doc. nr. 14) and Accomplishment summary
(Doc. nr. 10). It should be noted that the contents of the SCM and SQA
plans (Doc. nr. 5) can be extracted from the NLR standard Project
plan.

**4. CONCLUDING REMARKS**
The NLR standards for the development of information systems are to a
large extent compatible with the guidelines given by DO-178A. Docu­
ments not foreseen by the NLR standards are a Plan for software
aspects of certification and an Accomplishment summary.

Considering the overall certification process, remarkable little
attention is given to the hardware development itself. The hardware
safety assessment takes account of failures through aging, but just as
for software, the hardware design may also have residual errors. These
errors need to be minimized as well. The NLR standards for the devel­
opment of information systems are also applicable to the development
of hardware. (Under the understanding that the Accomplishment summary
needs to be added). This guarantees orderly development and managem­
ent.

Although the purpose of DO-178A is to describe techniques and methods
for software development and management, it is felt that the
guidelines given present more information about what needs to be done,
rather than how it can be done. One goal of revision B is improvement
on this point. It should be noted that although the application of
DO-178A assures a controlled software development process, it not necessarily guarantees a high level of quality of the produced software. Apart from the quality assurance measures and supporting tools, quality also depends on the capabilities and motivation of the software engineers and support from the management level.

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APPENDIX A DLPU ENVIRONMENTAL SPECIFICATIONS

1. Temperature and altitude

Category A1:
Equipment intended for installation within a controlled temperature and pressurized location on an aircraft which pressures are no lower than the altitude equivalent of 4600 m. This category is also applicable to aircraft that are not pressurized and operate at altitudes no higher than 4600 m.

Low operating temperature: -15 °C
High operating temperature: +55 °C
High short-time operating temperature: +70 °C
Loss of cooling test: +30 °C
Low temperature ground survival: -55 °C
High temperature ground survival: +85 °C
Altitude: 4600 m

2. Temperature variation

Category C:
Equipment in a temperature-controlled internal section of the aircraft.

Temperature change rate: 2 °C/min.
Low temperature: -15 °C
High temperature: +55 °C

3. Humidity

Category A:
Equipment intended for installation in civil aircraft, non-civil transport aircraft and other classes of aircraft in which the severe humidity environment is normally not encountered.

Humidity: 85 - 95 %
Temperature: 30 - 50 °C
Period: 2 cycles of 24 hours

4. Shock

Envelope: half sine wave
Amplitude: 6 g
Duration: 11 ms

5. Vibration

Sinusoidal test:
5 - 54 Hz: double amplitude = 0.010 in.
54 - 2000 Hz: acceleration amplitude = 0.5 g
Frequency sweep: 1 oct./s

Random test:
10 - 500 Hz: 0.0005 g/Hz
500 - 2000 Hz: -3 dB/oct.
RMS acceleration: 0.76 g

6. Magnetic effect

Category A:
Distance between equipment and magnet 0.3 - 1 m for a deflection of 1 degree.

7. Power input

Category E:
Equipment requiring only AC input power.

Voltage and frequency:
122 V / 420 Hz for 30 min. and 104 V / 380 Hz for 30 min.
Voltage modulation:
3.5 V peak-to-peak difference.
Frequency modulation: 3.5 V peak-to-peak difference.

8. Voltage spike conducted

Category B:
Equipment intended primarily for installation where a lower standard of protection against damage by voltage spikes is acceptable.

Test point: power input
Signal characteristics:
0 → 230 V (at t = 2 μs)
zero crossing: t = 10 μs
duration: 50 μs
repetition rate: 10 Hz and 50 Hz

9. Audio frequency conducted susceptibility

Category E:
Equipment requiring only AC power input.

Test point: power input
Signal characteristics:
750 Hz - 15 kHz: U_m > 5 % of 115 V

10. Induced signal susceptibility

Category Z:
Equipment intended primarily for operation in systems where interference-free operation is required.

Test point: 15 cm from equipment
Magnetic field: 20 A - RMS at 400 Hz
Test point: interconnecting cable
Magnetic field: I x L = 30 Am at 400 Hz, reducing to 0.8 Am at 15 kHz
Test point: interconnecting cable
Electric field: V x L = 1800 Vm at 380 - 420 Hz

11. Radio frequency susceptibility

Category Z:
Equipment intended primarily for operation in systems where interference-free operation is required.
Conducted
Test point: power input
Signal characteristics:
90 kHz - 2 MHz: 100 mV - RMS, 80% AM mod.
2 MHz - 30 MHz: 500 mV - RMS, 80% AM mod.

Test point: interconnecting cable (cur. inj.)
Signal characteristics:
15 kHz - 100 kHz: 100 mV - RMS, 30% AM mod.
100 kHz - 2 MHz: 100 mV - RMS, 80% AM mod.
2 MHz - 30 MHz: 500 mV - RMS, 80% AM mod.
30 MHz - 150 MHz: 100 mV - RMS, 80% AM mod.

Radiated magnetic fields
Test point: equipment/interconnecting cable
Signal characteristics:
15 - 100 kHz: 5 V - RMS, 30% AM mod.
100 kHz - 2 MHz: 10 V - RMS, 80% AM mod.
2 - 10 MHz: 10 V - RMS, 80% AM mod.
10 - 35 MHz: 10 V - RMS, 80% AM mod.

Radiated electric fields
Test point: n.a.
Signal characteristics:
35 - 400 MHz: > 5 V/m, 80% AM mod.
400 - 1215 MHz: > 5 V/m, 30% AM mod.

Note: Modulating signal is a 1 kHz sine wave.

12. Radio frequency emission

Category Z:
Equipment intended primarily for operation in systems where interference-free operation is required.

Category B:
Equipment intended primarily for operation in systems where interference should be controlled to a tolerable level.

Conducted
Power lines:
150 kHz: 100 dBµA/MHz
20 MHz: 50 dBµA/MHz
30 MHz: 50 dBµA/MHz

Conducted
Interconnecting cable:
150 kHz: 120 dBµA/MHz
20 MHz: 70 dBµA/MHz
30 MHz: 70 dBµA/MHz

Radiated
(35 MHz)
25 MHz: 55 dBµA/MHz
200 MHz: 70 dBµA/MHz
125 MHz: 65 dBµA/MHz
ARE NEW TECHNOLOGIES IMPROVING SERVICE QUALITY IN GERMAN PUBLIC TRANSPORT?

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Abstract: New technologies promise to accelerate public transport as well as to improve its service quality. I would like to show that the safety of public transportation, especially service quality, cannot be increased without a humane design of work and technology.

I. The Implementation of New Technologies in German Public Transport

In Germany new technologies have been implemented in public transport since the 1980s. Public transport firms have employed new technologies in all fields covering transport analysis and planning as well as operation and vehicle maintenance (Minssen/Hansen 1989; Topp 1985; Girau 1983). Producers of new public transport technologies and public transport firms stress mainly three reasons for introducing new technologies. First, the possibility to reduce public transport costs and expenditure by using new technologies has been promising to many a German public transport firm. Because of the financial crisis of local communities, in many cases the owners of urban public transport companies, the public transport sector has also been set under financial pressure to reduce costs. The implementation of new technologies is combined with hopes to gain more transparency over potentials to improve the effectiveness and efficiency of public transport as well as promises to save indirectly personnel costs (Becke 1991; Berger 1988). Although new technologies are in part quite expensive, public transport firms can afford them because they are subsidized by the German Traffic Financing Act For Local Communities. According to this act 80% of the investments for new technologies are often financed by Federal governments (Vornheim 1987).

Secondly, the user argument is put forward to bring in new technologies. They are said to ease the user’s work. For instance EDP - assisted data analyses and planning methods enable users
to improve their capacities to test a wider range of planning alternatives and rationalize highly-standardised manual work processes (Minssen 1988; sfs/Trans TEC 1992).

Last but not least, the customer argument is underlined. By introducing new Technologies, public transport firms promise their (potential) customers an acceleration of public transport, more conveniences, improved technical safety of transportation and a greater extent of just-in-time transfer guarantees. These promises partly match with customers' demands for public transport systems (Held et al. 1981) but it is an open question whether the development of new Technologies is sufficient to meet customers' demands.

A good example of new technologies which are supposed to contribute to alter the modal split in favour of public transport by increasing its attraction for (potential) customers (Bollhöfer 1988) are bus control systems: a bus control system is based on a permanent computer-assisted connection between busses and the transport controller. By means of the logical respectively physical location of busses, the controller is able to fix the exact position of busses with the precision of the length of a bus. For instance the exact position of a bus can be fixed in case of a physical location by beacons installed alongside bus routes. A bus emits data information about his actual position by the support of beacons. The position of a bus is recorded every twenty seconds and transferred to the bus control office by data communication. The information about the location of a bus is processed by the controller's computer. A computer programme compares the actual bus position with the bus position which is expected on the basis of the timetable. The result of this comparison appears on the controller's monitor. If the temporal difference between timetable and the actual position of a bus passes over a tolerated margin of time (e.g. five minutes) the controller's attention will be drawn on bus delays by an optical or an acoustical signal. It is the controller's task to detect delays and traffic disturbances right in time and to cope with them by organising and sending out substitute busses - so far as possible. The information about his actual position is transmitted to the bus driver by radio communication or as visualized information on the display of the integrated on-board-information system, which is often installed on busses driving on routes covered by a bus control system (Minssen/Hansen 1989).

I have described the bus control system more precisely because I want to discuss what kind of impacts it has on the working conditions of driving personnel as well as on the safety of transportation, especially the service quality of public transport. Are the expectations of public transport managers and even shop stewards to increase the customer's demand for public transport services by using new technologies far-fetched or are there good chances of meeting them? Well, there are quite a lot of factors influencing the service quality of public
transport such as traffic policy and town-planning (Lowe 1992). I would like to concentrate on the importance of a humane design of work and technology for the safety of public transport and its service quality. The safety of public transport does not only include technical aspects but also the dimensions of public transport work and service quality. An implementation of new technologies which aims at increasing the attraction of public transport has in my opinion also to take into consideration working conditions and service aspects.

I would like to discuss the relation between the design of work and technology on the one hand and the service quality of public transport on the other hand with regard to the very first German study about public transport work and the impact of new technologies on working conditions. This pilot study, which was financed by the German Ministry of Research and Technology, was carried out by an interdisciplinary team of social scientists, traffic engineers, economists and physicians between 1987 and 1989. The Landesinstitut Sozialforschungsstelle Dortmund was in charge of the pilot study and responsible for the social scientific research tasks. The project based on ten case studies of public transport firms all over former West Germany including different types of urban public transport firms. Nearly a thousand bus-, tram- and tube drivers as well as circa 400 maintenance workers were interviewed by standardized questionnaires. Moreover, a hundred group discussions and qualitative interviews with managers, shop stewards and employees were carried out (Minssen/Hansen 1989; Minssen 1988; Minssen et al. 1988).

II. Bus Drivers' Work Between Autonomy and Time Pressure

In Germany bus drivers cover a wider spectrum of activities: first of all, bus drivers are to drive passengers safely and comfortably through urban traffic; they often have to cope with difficult traffic situations in order to avoid traffic accidents and guarantee the safety of transportation. This task is the more difficult the more numbers of car traffic rise within inner cities. Furthermore, bus drivers announce bus stops and open and close bus doors at bus stops taking care that no customer is harmed. Last but not least, bus drivers are the most important link between public transport firms and their customers. For instance bus drivers sell tickets to customers, give them information about public transport timetables and ways to go. In the evening hours the driving personnel also has to check tickets.
Driving buses is a very isolating kind of job; bus drivers have little chances to communicate with their colleagues at work in comparison with their contact to customers. But this kind of communication is not very intense either because of the permanent change of passengers. Nevertheless, our pilot study shows that conflicts with customers often happen; only 17% of the bus drivers told us they had not had any argument with passengers within the last two or three months before being interviewed. The communication with passengers is often difficult because bus drivers are their very first contact to public transport firms complaining about delays and missed bus connections (Minssen 1988, 19).

Although bus drivers have to keep in mind service regulations, their field of activities offers chances for the self-regulation of their work. A lot of traffic situations cannot be coped with by just following general regulations but require the bus driver's decision-making. For instance bus drivers have to decide whether to accelerate or stop the bus if traffic lights turn to amber. Moreover, there are grey areas of decision making which are not clearly forbidden by regulations. In all public transport firms of our pilot study we found that bus drivers often contribute to passengers' safety of transportation by using their radio set to guarantee transfers: in case of minor delays a bus driver can ask a colleague to wait a short time at a certain bus stop in order to guarantee the transfer for a customer.

The relatively wide range of decision making during work results mainly from the bus drivers' co-existence with private car traffic in cities and suburbs. The confrontation with private car traffic implies that bus drivers have to react and decide quickly and safely in unforeseen traffic situations. The direct confrontation with car traffic is the main reason why bus drivers' work autonomy is combined to a great extent with strong feelings of responsibility especially for the customers' safety and security of transportation. In our study we found out that bus drivers' feeling of responsibility is obviously stronger in comparison with drivers of track-guided local transport systems (e.g. tube or tram). Track-guided means of transportation imply less or even no zones of direct contact with private car traffic.

The great extent of bus drivers' work autonomy refers just to their field of activities as well as their chances for decision making at work, but it does not coincide with autonomy in temporal aspects. Bus driving is characterized by a rigid time structure because drivers are expected to keep to timetables. The end to be punctual is often missed because of a large number of cars. More than forty per cent of the bus drivers told us that keeping to timetables is often a problem; even 77% have often or sometimes to wait for a feeder bus. Hence it follows that delays often consume bus drivers' breaks and cause psychological stress to be punctual. 57% of the bus drivers often feel that they are working under time pressure. Most of them are of
the opinion that time pressure has increased because of rising numbers of private car traffic and - nevertheless - reduced period of time between bus stops (Minssen 1988; Bamberg 1989).

III. The Impact of Bus Control Systems on Drivers’ Working Conditions and Service Quality

With regard to our pilot study I will discuss the influence of a bus control system on working conditions as well as on service quality. The implementation of bus control systems alters the mode of control: first, bus control systems produce information about the driving process without being dependent on the bus drivers’ contribution (Malsch 1987, 81; Bamberg 1989, 18) because the bus control system is self-sufficient in generating and transmitting information about the actual position of a certain bus. A bus control system enables a permanent external control over the bus drivers’ adherence to timetables. In conventional public transport firms, where no bus control systems are employed, the external control of bus drivers is limited to the bus drivers’ behaviour and ways of driving by inspectors on buses; this kind of control is not permanent but very selective. The use of bus control systems includes a loss of self-control bus drivers exercised on information over their vehicles which were not available for controllers. Bus drivers thus lose a “source of uncertainty” they controlled towards the Transport Control Office (Minssen 1991, 237; Crozier 1990, 299).

In our pilot study we asked drivers about their feelings towards external control at work. It is not too astonishing that drivers on routes covered by a bus control system significantly more often felt a strong or very strong external control (44 %) than their colleagues driving on routes without a bus control system (23 %). A feeling of being controlled is reinforced if bus drivers have to imprint a personal identification code in their on-board-information system before starting work, if delays are being permanently shown on the display of the on-board-information system and if the transport control office turns to them more often in the case of delays. The feeling of being controlled does not necessarily coincide with external control; for instance the personal identification of drivers before starting work was not referred to by any public transport firm of our sample in order to control the work performance of drivers. Nevertheless this feeling of control includes negative consequences for the relationship between driving personnel and customers: the more drivers feel controlled at work the more they are dissatisfied with their work. If bus drivers do not feel content with their work
because of the feeling of external control their behaviour towards customers might be
influenced in a negative way. Strong feelings of external control foster a shift of attitudes on
work because drivers might in the first place tend to avoid any delay and seek to keep to
timetables; their service tasks towards customers will then be of minor importance which
might lead to a loss of service quality (Minssen 1988; Bamberg 1989; Becke 1991).

The implementation of bus control systems also restricts the bus drivers’ work autonomy,
especially its informal grey areas of decision making at work. In public transport firms with a
bus control system you can generally find a selective radio communication, i.e. bus drivers
cannot any longer secure transfer guarantees by direct radio contact between themselves but
only the controller of a Transport Control Office can establish communication with bus
drivers. Bus drivers do not only lose another source of uncertainty towards controllers, but
their isolation at the work place is also increased. The non-selective radio communication
implies the advantage that drivers are involved in the "internal life" of their public transport
company listening to radio communication. But there are also some drivers who appreciate a
selective radio communication because they feel disturbed by the voices and noises stemming
from a conventional radio communication.

The introduction of bus control systems equipped with a selective radio communication cuts
off chances to guarantee transfers directly between a bus driver and his colleague of a feeder
bus. In case of customers wanting to change buses at a certain bus stop a bus driver has to
inform the control office by imprinting a key for radio contact on his on-board information
system. The controller can realize the bus driver’s request for radio contact on his monitor.
But if there were other requests queuing in line a bus driver has to wait for his request until it
is his turn. In the meantime customers might have missed their feeder bus. Transfer
guarantees as an important aspect of public transport service quality can apparently suffer by
using selective radio communication (Minssen 1988, 83; Becke 1991).

In our pilot study we did not interview customers about the effects of bus control systems on
service quality. However, we asked bus drivers on routes with and without bus control
systems whether they had had any trouble with customers within the last three months before
our interviews were carried out. The result might be surprising because there are hardly any
differences between the two groups of drivers: over 85% of drivers with or without bus
control systems told us they had trouble with customers because of problems to keep to the
timetable. About 70% of the bus drivers interviewed with and without driving on routes had
been angry with passengers because of complaints about delays or failed transfer guarantees
(Minssen 1988, 89-91). These results raise at least doubts about the argument that new
technologies generally and bus control systems in particular improve the service quality of public transport. Whether new technologies contribute to an improvement of service quality depends among other aspects on a humane design of work and technology.

IV. Outlook: Aspects of a Humane Design of Work and Technology in Public Transport

With regard to the implementation of bus control systems I would like to indicate some starting points for a humane design of work and technology in public transport. The feeling of strong external control was identified as a psychological stress factor as well as a possible restriction for an improvement of service quality. The extent to which bus drivers feel externally controlled can be reduced by a more flexible design of bus control systems: for instance there is no need to let bus drivers key in their personal identification code starting work as some examples of public transport companies of our sample using a bus control system show. Moreover, feelings of external control can be reduced if on-board-information systems are designed in a way that bus drivers can choose on their own whether to work with a permanent visual indication of temporal differences between the actual position of their buses and timetables or not. Some bus drivers even appreciated this permanent indication of time.

Avoiding the reasons for strong feelings of external control could foster the bus drivers to concentrate more on individual contact with customers than just keeping strictly to timetables. This aim can only be reached if bus drivers' time pressure is reduced. In our study we found out that bus drivers appreciated bus lanes and an actuation of traffic signals for buses as means to reduce time pressure. A bus control system without supporting acceleration measures for public transport makes hardly any sense. Moreover, a bus control system would be ineffective if there were no substitute buses available for a controller to cope with extreme delays and traffic disturbances (Minssen 1988; Bamberg 1989).

Another example of a humane design of technology would be to extend the bus drivers' work autonomy by offering options for an individual organisation of transfer guarantees among bus drivers. Therefore, radio communication systems could be designed in a way that enables bus drivers to switch between a selective and non-selective mode of radio communication. Such options for a direct establishment of transfer guarantees among drivers would improve the service quality for customers.
A further extension of bus drivers' work autonomy and field of activities should not be labelled with "lack of control" but with the future perspective of an improved service quality. For instance bus drivers' tasks include in many a German public transport firm the coordination with taxi services for customers. In the evening hours bus drivers can manage punctual taxi-transfer guarantees for night owls at each bus stop. The service quality of public transport systems could be increased if the bus drivers' field of activities was extended by additional coordination functions. For example it might be possible for bus drivers to guarantee transfers between different public transport companies or transport systems. By establishing radio contacts with local or regional train stations bus drivers could inform passengers directly about their next train transfers. This kind of job enrichment would possibly foster a change of bus drivers' work to mobility organizers.

Moreover, options for job rotation covering different work places could be experimented with. In Germany bus driving leads quite early to disability at an average age of fifty years and an average length of service of twenty years. Main reasons for disability are shift work, the confrontation with a large amount of private car traffic and deficits regarding the design of bus drivers' work place (Gießner/Weigel/Schmidt 1989; Ernst 1990, 28; Haas et al., 1989). Although a special model of more flexible work organisation for disabled and partly disabled bus drivers was successfully tested in Nuremberg (Gießner-Weigel/Schmidt 1989), there is a lack of integrated work organisation concepts for driving personnel which do not only include driving but also other jobs as for instance public transport attendancy or service and information functions (Ernst 1990; Tränkle/Bailer 1992). Such kinds of integrated job rotation require a permanent vocational training and planning of job rotation (Ernst 1990, 29), but they reduce bus drivers' disability and improve service quality for customers.

The modal split can be altered in favour of public transport systems if - among other aspects - a humane design of work and technology is combined with the development of new service concepts for public transport. Such future steps, however, are based on the necessity of direct participation for public transport employees as well as customers (Becke, 1991; Pagano/Verdin 1987; Monheim/Monheim-Dandorfer, 1990).


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FUTURE TRENDS
RELATIONSHIP BETWEEN ACCIDENTS AND ROAD USER BEHAVIOUR: AN INTEGRAL RESEARCH PROGRAMME

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Abstract

The analysis of accident statistics and the study of road user behaviour are the traditional methods of road safety research. Neither of these involve direct observation of accidents. A research programme has been designed to gain insight in the generation process of traffic accidents as well as to compare the traditional methods of road safety research. The first goal asks for long term day and night video recordings at a number of locations. In view of the second goal other methods of research have to be applied at the same locations. This kind of research has been called the integral approach.

The design of the programme will be presented and the value of video recordings will be illustrated by three recordings of actual accidents.

Traditional approaches of research on traffic safety

Research on traffic safety takes the form of analyses of accident data or the study of road user behaviour. Both approaches have their advantages and disadvantages. The registration of accidents is limited in number as well as in the type of information. Many accidents (the less serious ones in particular) are not recorded. Circumstances, the sequence of events and the behaviour of road users in accidents are recorded in general terms only. Accident data can be supplemented with observations at the spot or interviews with eye witnesses. This can only be done on a small scale and necessarily only some time after the facts. In summary, this approach is more concerned with the consequences of accidents than with the accidents themselves. The behaviour of road users can be studied in a number of ways. The most serious limitation lies in the fact that all this behaviour does not result in real accidents. The aim of research on traffic safety, however, is to gain insight in the occurrence of accidents as a result of the behaviour of road users in their actual traffic situation. This limitation is only partly resolved by choosing the conditions of behavioral studies in accordance with accident statistics. In summary, this second approach is directed at events that have at best a tendency to result in accidents. Knowledge about the genera-
tion of accidents is obtained by combining the results of both approaches, neither of which involves direct observation of accidents.

The integral approach

In this situation there is a need for research in which accidents are studied in a direct way. Together with other institutes SWOV has elaborated the design of such a research programme. The goal of this research is to gain insight in the generation of traffic accidents as well as to compare the traditional methods of road safety research. The first goal asks for long-term video recordings during day and night at a number of locations. In view of the second goal other methods of research have to be applied at the same locations. This kind of research has been called the integral approach.

Selection of locations

The design of the proposed research programme has to meet a number of requirements, the first of which concerns the selection of locations. A number of locations is needed with a high number of accidents per time unit. Furthermore, these accidents should resemble each other in some ways and be different in other ways. Preferably, these accidents should represent a large proportion of all traffic accidents. Based on these considerations a choice has been made of urban intersections with high traffic volumes, partly with traffic lights, partly with priority signs. 20% of all serious traffic accidents occur at such locations. It has been estimated that in one year time ten of these intersections will have about hundred accidents, about thirty of which serious enough to be recorded by the police.

Selection of methods

The research methods to be applied in this programme have to be already proven in practice. They should also have a wide range of application. Finally they have to show essentially differing elements between them. Based on these criteria, a small number of methods has been selected. Traffic counts will be made from video tapes. Video recordings will also be analysed by measuring the Time-To-Collision (TTC): the time that is still available before two road users will meet at the same time at the same spot (provided neither of them takes evasive action). The length of this time period differentiates between encounters and conflicts. This method also measures the exact position, speed, change of speed, direction of movement and change of direction at successive moments in time (van der Horst, 1990). Additional video recordings will be made for the analysis of head movement data. Two other methods of conflict analysis will be applied based on human observations at the road side. One of these is DOC­TOR (Dutch Objective Conflict Technique for Operation and Research), a method which can be seen as the 'subjective' counterpart of the video-based TTC method (Kraay, van der Horst & Oppe, 1986). The other method is a
completely subjective judgement of the danger of an encounter in traffic (Kruysse, 1990). A totally different method is the reconstruction of accidents by means of road side inspections and interviews with eye witnesses some time after the accidents: the in-depth accident investigation (Stoop, 1991). Finally, all accidents and serious conflicts which are going to be recorded will be analysed by a team of traffic safety experts. This analysis includes an interpretation of the behaviour of the road users in terms of motivation, information seeking, decision-making and internal representation of the traffic situations. This, of course is not a standard method of safety research since such recordings have not been available before (with a few exceptions).

Selection of observation periods
Apart from the latter two methods, the application of all the other methods must be restricted in time to one or more relatively short periods of observation. These periods must have a high number of observable events per unit of time. This requirement has been translated as a high number of accidents per unit of time. Again, these accidents should preferably represent a large proportion of all traffic accidents (at this kind of locations). Accident statistics show that a first choice consists of the afternoon hours of weekdays during daylight. 40% of all serious accidents at urban intersections occur during these hours. To obtain a sufficient number of conflicts at each location, observations should last four days as a minimum.

Analysis of video-taped collisions
To demonstrate the approach of analysing the sequence of events that finally results in an accident directly from video, in this section three examples of video-taped collisions will be discussed. Collisions 1 and 2 were accidentally recorded during video-observations of road user behaviour in The Netherlands. The third collision was registered during an accident-recording study by the City of Helsinki with similar objectives as our proposed integral approach. In a period of 11 months they collected 9 accidents on tape. At another intersection 2 accidents were recorded within a one month period. The procedure in Helsinki to collect accidents required that there was made reference of an accident to the police. We anticipate a selection procedure that also enables the storing of minor collisions without the involvement by the police.

Rear-end collision at roundabout
The first example consists of a rear-end collision between two cars at a leg of a large-scale roundabout with roundabout traffic having right of way.
Collision 1: rear-end car-car at a roundabout.

**Accident registration**
The information that most likely is available from the accident statistics (if registered at all!) is very limited and will probably only include: rear-end collision, car-car, at roundabout, some information on road and light conditions, damage-only accident.

**Police report**
If the original police report is accessible, some additional information may be available, such as a rough situational drawing, the direction the vehicles involved are coming from and going to, and as the reason why the accident occurred 'insufficient distance keeping'.

**Event description from video**
The vehicle in question (VEH1) is approaching the roundabout at a low speed, while the second vehicle (VEH2) is nearing VEH1. VEH1 is preceded by three vehicles that enter the roundabout in front of him. VEH1 stops (as does VEH2) for a vehicle at the roundabout, gives way to six other roundabout vehicles, accelerates for a very brief moment, but then waits for a seventh vehicle. VEH2 starts to accelerate at the moment VEH1 makes his small movement, and runs into VEH1 that stopped again. VEH2 pushes VEH1 several meters forward.
Subjective interpretation

VEH2 is nearing VEH1 with a relatively high speed. From the rather abrupt slowing down one may conclude that the driver of VEH2 is in a hurry (or is an aggressive type of driver). Apparently, VEH2 orientates himself towards the seventh vehicle on the roundabout, once he got the 'go' signal from the small movement of VEH1. VEH2 is missing the second stop by VEH1. The obtuse connection to the roundabout may well be contributing to the occurrence of this collision.

Right-angle collision at priority intersection

Collision 2: Right-angle accident at a priority intersection.

Accident registration

Information from the accident statistics on this accident comprises probably only the following items: car-car, right-angle collision, failure of giving right of way, damage only.

Police report

A raw situational sketch that is often included in the police report, may indicate the directions the vehicles involved are coming from, who was failing to give right of way, and sometimes the type of intersection is mentioned.

Event description from video

The vehicle from the minor road (VEH1) is approaching the intersection with a
normal speed, comes almost to a full stop at a place beyond the yield markings on the road pavement. A vehicle from the left (VEH2) starts braking for about 1 s at 3 s away before the actual collision occurs, but accelerates again after VEH1 has reached a very low speed. At the moment VEH2 is just in front of VEH1 (and a third vehicle coming from the right is just entering VEH1's viewing area), VEH1 accelerates and runs into the right side of VEH2. VEH1's view to the left is restricted by a van that is parked at the corner for about 10 minutes.

**Subjective interpretation**
The reason why VEH2 starts braking may well be that he is probably anticipating a potential right of way error by VEH1. He concludes from the near stop by VEH1 that he has been noticed and decides it is safe to proceed. The driver of VEH1 is displaying behaviour that is rather typical for a normal right-hand-rule intersection, viz. that one only is looking to the right in search for other vehicles (Janssen et al., 1988). So he may have missed VEH2 completely either because he was not aware of the vigorous priority regime at this particular intersection, or because he looked at the left too early. It seems as if VEH1 decides that it is safe to accept the gap in front of the vehicle from the right, while completely overlooking VEH2. From this event it is clear that several measures for improving the intersection lay-out can be proposed.

**Car-pedestrian collision at zebra crossing**

Collision 3: Car-pedestrian accident at zebra crossing of a signalised intersection.
Accident registration
Accident statistics would probably provide you with the following data: pedestrian-car collision, injury accident, zebra crossing involved, pedestrian from the left was running the red light, slippery road surface.

Police report
The police report would probably give some more details, such as at which zebra crossing the accident occurred, perhaps that the pedestrian started crossing all at a sudden, and, consequently, the car driver was not able to avoid a collision.

Event description from video
At a dual carriageway intersection with a wide median containing streetcar tracks, two pedestrians enter the first carriageway zebra near the end of green (that can be deducted from the behaviour of other road users). They also cross the median, but wait at the median curb of the second carriageway. A number of cars is waiting for making a left turn. For a relatively long time no straight-on traffic is present. All at a sudden one of the pedestrians starts running just at the moment a vehicle is approaching the zebra crossing on the left straight-on lane. The vehicle starts braking at a very late moment just before the frontal collision with the pedestrian occurs. A vehicle in the right lane is able to brake in time for the pedestrian lying on the road.

Subjective interpretation
While looking at this accident, one may wonder why the pedestrian starts running so suddenly. A plausible explanation is that he wants to catch the bus across the road. A careful inspection of the bus behaviour reveals that the bus moves forward a little bit just before the pedestrian starts running. Similar to collision 1, it seems as if relatively small movements in an expected direction people already trigger and focus on one particular sequence of actions that, once started, are difficult to interrupt. Moreover, the line of waiting left-turning cars together with the absence of straight-on traffic for a relatively long time may well have the pedestrian let come to the conclusion that the signal for the cars already had turned red.

Conclusions
The traditional approaches of traffic safety research (analysis of accident statistics, behavioural studies) do not involve direct observation of accidents. As a result the chain of events and the behaviour of road users resulting in an accident can only be hypothetically inferred. Long term video recordings open the possibility for direct observation of accidents. An integral research programme has been designed with long term video recordings, together with traditional methods.
The value of video recordings of accidents is illustrated with three cases, showing
that the recordings:
- provide detailed information on circumstances and chain of events,
- can be analysed with quantitative measures (e.g. Time-To-Collision), and
- can be used for a detailed, subjective interpretation of the behaviour of road users.

The integral approach cannot be applied as a standard method, but will lead to a more appropriate application of traditional methods (such as conflict observations), based on a better theoretical understanding of the generation of accidents.

Acknowledgment

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0. Abstract

In 1991 the Dutch Ministry of Transport, Public Works and Water Management concluded that its policy regarding road-safety should be sharpened in order that its goal set for road-safety in the year 2010 would be achieved (i.e. 50% reduction of dead and 40% reduction of wounded persons in comparison with 1986). This new policy is being called "Intrinsic Safety". The important elements of this course of action are:

- A greater degree of control of structural developments.
- Increased action to prevent accidents rather than that which reduces the severity of the consequences of accidents.
- Greater attention for an integral approach of traffic safety, through influencing all kinds of decision makers outside the realm of traffic safety.
- Not viewing and treating the human aspects, the roads and the vehicles in isolation, but primarily focusing attention on the interaction between these components.

At the moment the Ministry has inaugurated some actions, which will be a more specific elaboration of "Intrinsic Safety". In this paper we will try to analyze whether this new policy is a totally new concept rather than an intensification of the old course of action. Furthermore we will discuss a few problems, which may occur, when the 'Intrinsic Safety' approach will be elaborated in the near future.

For example:

- How do we make sure that chosen measures (e.g. decisions concerning the infrastructure) will be the most effectual one in relation with safety?
- Is the organisation at this moment sufficiently fit to work on an 'intrinsically safe traffic system' or is it inappropriate? (e.g. presently there is an increasing tendency of decisions being made by regional departments rather than by central government)
- Are we in the possession of sufficient knowledge concerning the interactions between the several goals of traffic policy so that actions taken in relation with one goal (e.g. reducing air pollution) will not have a negative effect on traffic safety?

1. Striving for intrinsic road-safety to sharpen traffic safety policy

In 1991 the Dutch Minister of Transport issued the third national traffic safety program. As the increase of the yearly amount of traffic casualties lead to the conclusion that without sharpening traffic safety policy, the government would not reach its goal set for traffic safety in the year 2010 (i.e. 50% reduction of dead and
40% reduction of wounded persons in comparison with 1986), a new approach of traffic safety was announced, in addition to an intensification of the current policy. This new approach being described as aiming for an intrinsically safe traffic system.

In the 'traditional' approach, traffic safety is considered in relative isolation as one of several problems in the traffic and transport sector. A thorough analysis of the safety problem (primarily based on registered safety figures) forms the basis for the identification of a set of central issues in road safety policy. Attention is concentrated on specific categories of traffic participants (i.e., vulnerable road users like children and elderly persons), on specific dangerous traffic situations/locations (infrastructure), and on specific dangerous traffic behaviour (driving while intoxicated, speeding). Accident registration figures however only reflect the final stage of traffic processes, as they do not give insight into the ways accidents emerge, and do not provide information about the coincidence of events that preceded the accidents. Accidents may be considered literally as accidental results of events preceding them. Therefore, by developing measures primarily based on the end result of traffic processes (accidents) the traditional approach may be considered as fighting symptoms. Locations on which many accidents occur are reconstructed in order to prevent occurrence of new accidents like those registered in the situation before reconstruction. Measures aimed at reducing speeding consist primarily of influencing drivers of motorised vehicles by way of enlightenment and (sophisticated forms of) police enforcement, as far as possible in combination with road reconstructions in order to elicit the desired speed.

The real causes of traffic safety tend to remain out of sight, as a result of which more structural solutions of traffic unsafeness may not be achieved.

The new policy of intrinsic road safety on the other hand takes the view that analysis of the entire traffic and transport system should be the starting point of tackling traffic safety. In comparison with the traditional policy the approach of intrinsic road safety has a more structured character. The leading idea being, that safety should be built in actively and before hand in the traffic and transport system. This implies that all variations within the system should be tested in terms of safety effects before these are implemented. If the test turns out to be negative, implementation should be withheld. Intrinsic road safety thus aims at directing further development of the traffic and transport system by means of safety as a criterion. In all areas which are related to the traffic and transport system, safety should be a basic factor in decision making. This not only concerns decisions strictly within traffic policy, but also decisions in adjacent areas, e.g. in town and country planning. Eventually, traffic safety should become a hard condition in further developing the traffic and transport system.

The table presents a review of the main differences between the traditional safety policy and the intrinsic safety approach.

The most important difference between the two approaches concerns the phase of the traffic process that is taken as starting point. The real causes of accidents are to be sought higher within the system: not with the individuals actually involved in accidents, but with those who create the situations in which eventually routine behaviour of traffic participants appears to be unsafe. The following example may be
Table: Comparison of traditional traffic safety policy with intrinsic road safety

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<thead>
<tr>
<th>Traditional</th>
<th>Intrinsic Safety</th>
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<tr>
<td>* Safety figures starting point</td>
<td>* Analysis of total traffic system</td>
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<tr>
<td>* Safety as isolated problem</td>
<td>* Safety as structural aspect of traffic system</td>
</tr>
<tr>
<td>* Symptom fighting</td>
<td>* Fighting structural causes of unsafeness</td>
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<td>* Bottom up</td>
<td>* Top down</td>
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Illustrative. Consider the situation in which a primary school is being separated by a busy street from the residential area of the pupils. Within the traditional road safety policy, such a situation would be considered as starting point for measures to make sure that the pupils will reach school safely: school crossing guides, speed reducing measures, or perhaps a pedestrian tunnel. The intrinsic road safety approach on the other hand would imply taking into account already in the phase of planning of school locations the possible road safety effects. This would lead to not building a school on such a location in the first place, or making safe crossing provisions before hand if another location for the school would not be available. This relatively simple example may illustrate also that working at intrinsic road safety is considerably more complex than following the traditional approach. In the following paragraphs, we will describe some of the major obstacles that are to be taken to further implement intrinsic road safety policy.

2. Long term and short term aspects of intrinsic road safety

In recent discussions aimed at further developing the concept of intrinsic road safety, the question was raised whether it is possible to conceive a blueprint of an intrinsically safe traffic and transport system. Will it be possible to design a traffic system that while being entirely different from the current system, could be implemented in the long run and thus would constitute an alternative system in the future in which a perfect balance between desired aims and necessary conditions (safety, ecology) would be achieved? However, trying to view intrinsic road safety this way seems fruitless. It is not possible to foresee in sufficient detail the future developments in all relevant areas (technological, economical, demographical, town planning, etc.) separately as well as in relation to each other. This would be necessary if we ever should be able to design a new, consistent, intrinsically safe traffic and transport system. Actually, it is not even possible to imagine a definite point of time at which the traffic system would be developed into a stable state, complying optimally with all the requirements (amongst which perfect safety conditions). Conflicting interests, changing interests as well as the permanent development of new possibilities to cope with existing problems will always give rise to adjustments being required within the system. In this sense, the system will be permanently, at any point in time, in a state of further development.
On the other hand it is necessary to formulate explicit aspirations in order to direct short term actions towards intrinsic road safety. These aspirations must imply more than merely stating the reduced amount of traffic casualties. We must develop ideas about what will be the typical features of an intrinsically safe traffic and transport system, and only then we can formulate a strategy which will lead to the desired measures, enabling us to pass the stage of distinguishing short-term bottlenecks in road safety and applying isolated short term measures (in fact the traditional approach).

The difference between designing a blueprint of an ideal, intrinsically safe transport system and formulating aspirations for future intrinsic road safety is, that as the latter is a dynamic, cyclic process, the aspirations should be continuously adjusted as new knowledge and insight are made available.

Recently, the Dutch Institute for Road Safety Research (SWOV) has at the request of the Ministry of Transport produced a report, containing an exploration of possibilities for the government to approximate intrinsic road safety in the year 2010. This report, written in cooperation with several other major research institutes, describes a strategy based on taking hold of the traffic components people, vehicles, roads, regulations and organisation in an integral way. In an illustrative way it describes how policy in this way may better the traffic system so that the amount of traffic situations where human errors lead to accidents will be minimised and the severeness of the few accidents that still remain will be limited.

This survey of strategical options for traffic safety policy constitutes an important first step toward the elaboration of intrinsic road safety policy. However, it is necessary that more far reaching scenarios will be developed, in which relevant variables from other areas, influencing traffic and transport, will be incorporated (town planning, economy, ecology, demography, technology, etc.).

3. Public support as a prerequisite for intrinsic road safety

Traffic safety is a societal problem. Every citizen is user of the traffic system. So every citizen has an interest in making this system as safe as possible. On this basis the conclusion could be made that there is a firm public support for fighting traffic unsafeness. In practice however it is more complicated and in the Netherlands at least, a number of often contradictory arguments are found to explain why road safety in fact is not considered a major item in society.

In the first place, traffic accidents are often considered as a consequence of risks that are controlled by individual road users.

A second reasoning is, that traffic accidents are purely the consequence of coincidental factors which cannot at all be influenced by directed measures.

Thirdly, often is pointed at the fact that road safety in the Netherlands is already very high compared with other countries.

And finally, there is the problem of 'dilution' of the traffic safety problem: At national level, 1400 yearly traffic fatalities could be considered as a serious problem, but at local level the number of fatalities becomes rather small. Thus traffic safety policy on local level has difficulty in competing with other major local interests.

Nevertheless, if fighting for traffic safety is to be continued and even to be intensified in a more structural sense (as proposed in striving for intrinsic road safety), we must in the first place put very hard effort in (re)establishing broad public support for traffic
safety policy. This implies convincing everybody that major progress is possible in further increasing safety, but that it cannot be achieved at no cost. Structural improvement of traffic safety may imply asking sacrifices of individual road users as well as specific sectors within society that have interests relating to traffic and transport but not necessarily coinciding with traffic safety. For example, it is imaginable that part of motorist’s autonomy in driving behaviour (e.g. choosing driving speed) had better been substituted by automated systems (speed limiter) from the point of view of traffic safety. In order to make such measures possible, it is evident that society must be convinced that limiting the individual degrees of freedom indeed will pay off in terms of traffic safety. In the same way, economic interests of the traffic and transport system should be confronted with safety interests. Problem is, that traffic safety lacks a powerful lobby in society. Of course we have road safety associations, promoting attention for road safety. But they do not represent a real powerful factor in the sense that they are backed up by major parts of society. In fact, they often largely depend on subsidies from government.

Politicians therefore have to play a major part in motivating society to pay active attention to furthering road safety. They should stimulate investments into road safety, not only by reserving government money, but also by convincing (and perhaps eventually even forcing) others to do so. They should stimulate others to weigh traffic safety against other interests. Possibly, they even are to take unpopular measures in order to further road safety.

Here, a dilemma is presenting itself. Politicians are chosen to execute the will of the people. This implies, that if the people does not give priority to traffic safety, politicians will have to hold out their necks in order to follow a different line of conduct.

4. Need for international synchronization

Road traffic does not end at national borders. Traffic and transport is being internationalised, as is the case in many other areas. The same goes for building in structural safety in the traffic and transport system.

In face of the unification of Europe, the participating countries have already for some years been busy trying to reach harmonization in several areas. One of these areas concerns traffic and transport. Progress has been made in harmonizing traffic regulations and legislation. In the near future, efforts in this respect undoubtedly will increase.

This also has consequences for road safety policy. Issuing specific national traffic regulation will become increasingly impossible. We can foresee that also traffic hardware (the infrastructure) will increasingly be assimilated between european countries. The car industry already tries to stimulate common european designing directives in order to prevent being confronted with all kinds of specific national demands.

As the character of traffic safety policy should be evolving from a following into a steering one (striving for intrinsic road safety), international cooperation and harmonization become almost compulsory.

For instance, we have already scenarios available to implement the concept of self explaining roads. These are roads, designed in such a way that the desired behaviour of road users is almost automatically elicited. In more sophisticated implemen-
tation, these roads will be provided with electronic devices communicating with motor
vehicles which consequently execute directly parts of the driver task. There is no
sense in trying to implement this kind of structural traffic safety measures on a
national scale. On the other hand, this kind of measures to improve road safety
seems indeed very promising.

5. The organization of intrinsic road safety policy

Making an inventory of the actors in society influencing the arrangement of the traffic
and transport system, it appears that their number is very extensive. However, the
three public administration layers (central government and regional e.g. local
administrations) are the primary steering bodies. All three of them each on its own
level have the responsibility to implement traffic and transport policy based on
weighing the very diverse interests involved. In order to do so, they all must listen to
the social groups representing the various interests involved and furthermore stand
up for general social interests lacking lobbyists (as may be the case for traffic safety).
Between the administration layers, responsibilities differ. Central government is
responsible for planning on a national level, formulating general strategies and
developing expertise based on scientific research. Also, it has to coordinate consis­tent
implementation of policy by other actors, mostly regional and local administra­tions.
Regional and local authorities are in turn responsible for the implementation of
central directives, but are also in charge of weighing the regional and local interests
involved.

Considering the respective roles of the three administration levels in implementing
intrinsic road safety, the most important prerequisite is a real concern for the need to
reduce unsafeness. Real support for traffic safety should at least be present at
central, regional and local authorities. This implies at least more than for instance
local administrators verbally or merely marginally in practice complying with demands
for furthering road safety in order to acquire the accompanying subsidies.
Eventually, real concern for attaining intrinsic road safety at all administration levels
should be reflected in actual investments, in attracting traffic safety expertise and in
active coordination of efforts.

6. Challenges for research

The most important challenge intrinsic road safety has to cope with is finding the real
structural causes of traffic unsafeness. Gaining knowledge of the variables that rule
traffic processes at all levels is therefore indispensable. Much knowledge about traffic
safety is already available. In the past decennia, scientists all over the world have
been preoccupied with developing knowledge of and methods for improving traffic
safety. Many solutions for actual safety problems have been proposed and progress
is still being made. We already know a lot about the most important components of
the traffic system: people, roads and vehicles. We have knowledge about human
functioning in performing traffic tasks. We have insight in the enormous potential of
human kind in this respect, but also in its fallibility. In fact, if we at this moment would
develop a traffic system, starting from a blank situation, we would without any doubt
be able to create a very safe system. Human potentials in this system would be
maximized by optimally equipping candidate road users by means of perfect educational programmes on the one hand and by limiting the degrees of freedom in traffic behaviour on the other hand.

The same goes for our knowledge of infrastructure and vehicle design. We know for example that major differentiation of speed, direction and mass is undesirable on roads on which the streaming function prevails. We also know how we must design such roads: our highways in most respects meet these demands. Otherwise we have been able to develop directives for designing safe residential areas, in which primarily by reducing speed different functions like playing and shopping go well together with traffic. Motor vehicles may be equipped with safety provisions like speed limiters, ABS, etc.

The main problem is, that the knowledge available is often fragmentary. There is great need of developing an overall model or theory, in which the existing knowledge on separate variables influencing the traffic processes is brought consistently together. On the one hand, we urgently need to know how for example vehicle measures like the ABS system influence the traffic behaviour of motorists. Is it likely that they will take more risks in traffic, knowing that their cars will assist them in emergency situations (risk compensation)?

On the other hand, on a more strategical level there is great need of knowledge about the relationship between decisions and measures taken in areas related to traffic and transport and their traffic safety implications. In the Netherlands for example, air pollution by motor vehicles as well as traffic congestion lead to the search of alternatives for certain categories of car trips (especially short trips and forensic trips). One of the options is stimulating cycling as a substitute for these trips. However, cyclists represent a very vulnerable category of road users in the Netherlands. In this particular case the conflict of interests is recognised by the dutch government, reflected in the formulation of bicycle promoting policy by adding the condition that unsafeness of cyclists must be decreased. But it is very likely that the safety consequences of many other decisions are often not recognised at all. In other words there is great need of instruments and methods by which we can predict traffic safety consequences of all kinds of measures, within traffic policy itself as well as within other areas, related to traffic and transport.

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PRACTICAL EXPERIENCE IN THE USE OF FORMAL METHODS FOR REAL-TIME SAFETY CRITICAL APPLICATIONS

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Abstract

The aim of this paper is to provide a practical introduction to formal methods and to explain their role in the safety critical system development process. Examples of the application of formal methods to practical problems will be used to illustrate some of the benefits, the actual costs and the practical limitations to the application of formal approaches.

Formal methods have many possible roles within the development process. It would be misleading to assert that formal methods are just techniques for verification of code although this is an important application. In the context of safety critical system development we are primarily concerned with system quality, ie fitness for purpose and its assurance. Software cannot be considered alone but must be taken in the context of the system in which it is to operate; the complexity of modern systems, particularly for real-time applications, is what makes the design and assurance difficult. Where systems are safety critical it is imperative that this assurance is effective.

In this paper, examples are used to show how issues of concern to the system engineer for these complex systems can be addressed by a formal approach. The most important of these is the meaning of safety in a system context and the requirements it imposes on software and the design process.

The paper concludes by discussing practical barriers to the exploitation of formal methods. Barriers exist in education, training, usable methods and tool support.

Introduction

The increasingly widespread use of microprocessor control in almost every field of system development has been motivated by the advantages of improved functionality, performance, response time, flexibility and reduced cost. In the area of safety critical transport applications these pressures also exist and critical systems are being designed with ever increasing reliance on computer control and, inevitably, software. However, these trends have been accompanied by concerns about the safety implications of software and the need to avoid errors in its development. A number of software development standards have been proposed, firstly to regulate the extent to which critical systems are based on software, and secondly to recommend best practice so that a high degree of confidence can be placed in those that are. UK defence standard DefStan 00-55 is one example of these, and is unusual in that it
places particular reliance on mathematically based ("formal") methods for software development.

In this paper, formal methods and their role in safety critical system development are discussed. A practical application of a formal approach to a real time safety critical system is discussed to illustrate the points made.

The nature of formal methods

Formal methods are mathematically based methods intended to assist in the system development process. A formal method has two parts:

- a formal part; this is a language or notation which is mathematically defined and that can be used to describe aspects of systems or their behaviour;
- a method part; ideally, this would be a prescriptive method indicating to the designer when, and how, design decisions should be made.

Very few prescriptive methods exist. This paper will focus on the ways in which a formal approach can be used to underpin the standard safety engineering process and the extent to which this can be achieved in practice.

The role of formal methods is probably best understood by illustrating their relationship with the design process. In order to assess the effectiveness of any design work performed during system development, it is necessary for the engineer(s) responsible to explain, at the appropriate review, first, how the various aspects of the design relate to the objectives set for it and second, how together, they satisfy them.

Formal methods can underpin this review process in two ways. First, the formal language allows the designer to state precisely both the design objectives and the design decisions taken themselves. Second, a formal approach also means that the effectiveness of the design can be demonstrated by providing a mathematical proof. This will be a logical argument justifying that satisfaction of the design objectives follows from the proposed design and the (documented) underlying assumptions made.

Therefore, the use of a formal approach may fulfil different roles and this must be considered when a formal method is selected. In many cases, the emphasis is mainly on specification. One example of the use of formal techniques in this context is for precise description of systems so that they can be standardised (where the formal description serves as a vehicle for communication). Another use is to impose a strict discipline in writing specifications forcing ambiguities to be resolved (so the formal approach serves as a vehicle for discovery). Formal languages for specification only need to be capable of defining the system behaviour or interactions adequately. Many studies have been carried out in which the benefits of rigour for
Precise communication and discovery have been reported. The use of formal description techniques for standardisation of communications protocols, for example, is established practice.

Where a formal approach is being used to underpin the assurance process, rather more is required. As well as being able to document the system design, it must be possible to articulate the justification that it meets its objectives, and this will require formal languages for analysis.

Similarly, the nature of the system must also be taken into account. Simple systems will be relatively simple to describe. If, for example, real time issues do not need to be considered in specification or in design, they will be amenable to a 'static' formal description. Real-time systems, on the other hand, where timing issues impact in a complex way in the design, impose a demand for a rich descriptive and analytical formal framework.

Further, if the formal assurance process is intended to bring additional confidence in the design, a degree of faithfulness is required of formal descriptions; only when the system description is lifelike will the correspondence between formally proved properties and desirable real world properties be convincing. The creation of faithful descriptions depends largely upon the approach of the analyst but can be limited by the underlying models in the formal technique being used. Finally, if the method is to be usable, it must be natural; the engineer using the method must be able to describe systems and document design justifications "in his own words" rather than in a way that is contrived to fit within the constraints of the method.

In practice, very few formal approaches meet these criteria for analytical richness, fidelity and naturalness. This has limited the extent to which they have penetrated into industrial practice. Very few applications of formal methods have attempted anything more than description. Proofs have been performed for some parts of the process, notably for the static verification of code with semi-automated tools, but this is only a relatively small part of the development cycle.

Failure to meet these basic technical criteria has been compounded by a lack of enabling infrastructure, in terms of awareness, expertise, training and machine support. This means that the extent to which even the immediate benefits of formal description can be exploited, without expert assistance, is limited.

The assurance of safety

When considering safety critical systems in particular, a number of key points should be raised in relation to the above.
1. Two communities have interests in safety critical systems. The first is the user community, which is concerned with the safety of the systems in use and needs to have confidence that the system as specified will operate safely; the other community is the supplier community, which must be confident that the system as supplied actually meets the requirements as set out by the user. The interests of these two communities converge in system quality, i.e. fitness for purpose and its assurance. The key contribution formal methods can make is to underpin this assurance process through the generation of proofs.

2. Safety is a system level issue. Assurance that software meets a particular specification, whilst being important, cannot provide a full demonstration of safety. The correct and safe operation of systems relies fundamentally on the complex interactions between embedded microprocessor(s) and all external entities such as communications, other computer systems, and the entities in the real world that give rise to hazards. All of these interactions must be taken into account when the system and software are specified and designed. A formal approach to underpin the safety assurance process must therefore be able to relate system behaviour to the most detailed aspects of design.

3. Safety systems are often embedded, real-time and inherently complex. It is this complexity which makes the design and assurance of the systems difficult. Software itself is not the problem; software is only used because it is the most effective way of building systems of the complexity that is required. Although there are safety problems peculiar to software (such as ease of change, which imposes requirements for configuration control), these are somewhat subsidiary to the issue of complexity. Many formal approaches steer away from the complexities of real time systems but it is for these that a rigorous approach is most required.

4. Many system properties that are desirable from a safety point of view are difficult to test. This is because they impose particular constraints on behaviour rather than purely functional properties. A well documented rigorous argument demonstrating that these properties are present is required to support any empirical evidence gathered.

Therefore, any development process model that proposed the use of formal methods for assurance of safety would be wrong to focus solely on software and would be wrong to focus on the production of formal specifications rather than proofs. What is required is an approach that can be used to relate the system safety issues to detailed design issues, can represent complex systems in a natural and faithful way, and subject them to rigorous analysis. Instead of viewing the formal analysis process as a set of rules that constrains the designer, a formal underpinning should have a liberating effect. In this way the designer will be able to explore more novel or creative solutions with confidence that, provided the assurance can be carried out, the performance and efficiency benefits they offer can be fully and safety exploited.
Fortunately, methods that can be applied in this way to practical problems are emerging. The remainder of this paper describes one application of such an approach.

Example application

Novel formal techniques were applied in a feasibility and design study for a communications subsystem (Slow Scan SSI) for use in conjunction with British Rail’s Solid State Interlocking (SSI), a computer based system for the direct control of railway points and signals. Some observations from the study, illustrating the points made above, are discussed below.

Slow Scan SSI is intended to provide an economical means of linking a control computer (‘interlocking’) to trackside sensor and actuator units. Instead of linking the components by a standard high grade electrical link it was suggested that a low grade, low bandwidth communications link could be interposed between the units for greater range. Instead of operating the usual roll-call protocol (analogous to Mil-Std 1553), a system which selectively transmitted changes to command and response messages only could be employed to reduce the bandwidth requirements significantly. The critical area in design was to ensure that particular timeliness properties of the existing protocol were not degraded in a way which can cause unpredictable or unsafe behaviour.

The operation of the roll-call protocol and the proposed system are illustrated in figure 1.
It was originally envisaged that a simple protocol could be devised in which only changes to command and response messages were transmitted across the lower grade link. Protocol converters at each end would maintain tables of current messages for each remote unit address and update them on receipt of change messages. It was proposed that the design of the system could be divided into two distinct parts: the communications service provided by protocols over the low grade link, and the application elements in the protocol converters maintaining and updating their application-specific information.

The intention was to specify top-level (ie end to end) functional and safety system requirements for the low grade system. Once protocols had been designed, their conformance to those design objectives could be demonstrated using a formal proof. The structure of such a design, in which the communications services are separated from the applications aspects, is illustrated in figure 2. This was the basic target solution envisaged.
The first step in the process was to specify formally top-level safety and functional requirements. Functional requirements describe the way the system is intended to behave under normal operation (e.g., in the absence of particular hazards or equipment failures). Safety requirements, on the other hand, describe the way the system is required to behave in any event, i.e., even in the presence of particular failures or hazards.

Identification of these requirements turned out to be more difficult than had at first been anticipated owing to the need to understand the implications of the timing properties exhibited by the low grade system. This was because the timing properties required for the train control application itself were not immediately apparent. For example, because the polling sequence is fixed in the standard roll-call protocol, it is possible for events occurring at the remote sensors to be reported to the interlocking in an order different from that in which they occurred. This is illustrated in figure 3 below.
Related events which are actually reported in the wrong order in this way could potentially give rise to unpredicted system behaviour; in practice they give rise to a constraint upon the actual protocol address assignment of the various sensors and the physical separation between them (determined by the speed of the trains). In this way, detailed timing aspects of the protocol become intimately related to actual physical processes in the control application. With an intermediate communications system in place, these relationships potentially become very complex and careful analysis was necessary before system requirements could be defined.

Exact criteria for safety in this context needed to be defined precisely as a basis for assurance. A tendency in the past to build interlocking systems by analogy with previous generations meant that very often the distinction between the two types of requirement was not fully recognised, and the system safety requirement was not made explicit. Once again, understanding of the overall control application was necessary before the actual safety implications of any behaviour of the low grade system could be analysed.

When it was attempted to establish more detailed protocol and software requirements it became apparent that the original intention of separating protocol aspects from application aspects was not achievable in a straightforward manner. Whilst protocol services could be specified at each of the layers in the stack (i.e., levels of service), there were also application aspects which were intimately related to each of the layers. One example of this arises from the fact that low grade link messages are not simply queued for delivery but can change whilst they are waiting to be served in response to updates.
arriving on the high grade link. Even when messages are re-transmitted after errors, the messages sent may actually differ as this is the only way that the desired timeliness targets can be met. This meant that, by contrast with the intended structure shown in figure 2, the final structure more closely resembled that shown in figure 4 below.

As the development proceeded, revisions to earlier stages became necessary. Formal and informal statements in the written requirements were maintained together; even though the top-level requirements changed during the design process, this change could be documented in the system requirements, the protocol design and the proof itself. Maintenance of this link vastly simplified the tasks of validation of revised requirements and configuration management.

Even though the definition of protocols and software had been carried out with the intention of verifying them against the safety objectives, construction of the proof was still not a routine matter. The need to justify every step in the argument exposed many implicit assumptions and misconceptions about the operation of the proposed system, and gave rise to revisions in the design. Most of these were quite minor and would have been detected by a normal programme of testing, but some were sufficiently subtle that it would have been possible for them to escape detection for a considerable time.

The properties that were proved represented safety properties of the overall system. These included:

- safety of behaviour under initialisation/reinitialisation;
- safety of normal operation;
- resilience to (ie safety in the presence of) hardware failure, communication errors;
- resilience to communications traffic overloads.

Overall, the effort required for construction of the proof was a moderate proportion of the total study effort (~30%) but most of this time was spent in revising the design to overcome shortcomings raised by the proof process (so it was time well spent). Without having conducted a parallel study, it is not easy to assess the relative cost benefits of spending the time on proof instead
of testing. The overall impression was that the level of up-front visibility of
the critical requirements and design issues was far greater than with more
conventional approaches and the ultimate quality derived from this visibility
was a significant gain.

Conclusions

Safety critical systems are often embedded, which usually means that they
operate under real time constraints and are complex. As a result, the
assurance necessary to demonstrate safety is both far-reaching (being end-to­
end in the development cycle) and difficult. An approach is therefore needed
whereby confidence can be placed in this assurance.

Practical studies have demonstrated that an approach based on formal
mathematical methods, when scoped in the right way, can provide visibility
and accountability in the assurance process that cannot be achieved in any
other way. These provide the level of confidence that is required for the
potential benefits of software based control systems to be safely exploited.

Practical barriers still limit the scale in which the techniques can be applied.
The generation of proofs for complex systems requires considerable expertise
and is still in the domain of the mathematician rather than the design
engineer. Tools to support this process are not available and will only ever
remove the routine, rather than the creative, activities. However, it must be
stressed that real time systems present difficult design problems, and their
development will continue to be a demanding engineering process. A formal
approach will allow the engineer to articulate his intuition rather than act as a
substitute for it.
NEW TECHNIQUES
Accidents; In-Depth Analysis, towards a method AIDA?

1. Introduction

Accidents are the dominant phenomenon in the perception of a malfunctioning interaction between man and machine. However, accidents are not easy to investigate. Not every accident is registered, a researcher seldom witnesses an accident personally and can only do his research on a-posteriori basis. Accidents are hard to simulate in a laboratory and it is difficult to predict where and when they will occur. Therefore, in road traffic accident research, reliance has been traditionally placed upon the statistical analysis of large volumes of aggregated accident data and on the monitoring of safety levels.

The introduction of the concept of Sustainable Safe Traffic and Transportation Systems causes a shift in attention from the individual components of road, man or vehicle towards the transportation system as such and emphasizes the importance of the design phase of the system. This shift in attention to the design phase, additionally to the use phase, is emphasized moreover, by the objective of the Dutch government to reduce the amount of accidents by 25% by the year 2000. Such an objective cannot be obtained by conventional approaches alone. These developments require a better understanding of the accident processes as a basis for intervention (Oude Egberink 1987)

Due to the introduction of information technology and modern management and logistic concepts, the traffic processes themselves become subject to research. Accidents are no longer considered as unique and incomprehensible events but are defined as undesirable
deviations from the transportation processes themselves (Koornstra et al. 1992).

1.1. In-depth analysis
Originating from the urge to take disciplinary action against the man in charge on the bridge or in the cockpit, the in-depth analysis of accidents has become a solid basis for a better understanding of accident processes. This type of research has a long and fruitful history in aviation, shipping and rail transport, encouraging technological development, legislation, training of operators and scientific research. The objective of this research is to learn from accidents and to prevent the occurrence of similar accidents in the future. In-depth analysis in these transportation systems aims for the goal of prevention, rather than the allocation of blame and liability.

In contrast to other transportation systems in Europe, in-depth analysis is in Europe seldom applied to road safety research, although the NTSB approach in the USA has proven to be successful (NTSB 1981). Several attempts have been made to develop this research technique but due to theoretical and practical reasons, have not yet lead to a generally applicable method (Greyson and Hakkert 1987, Oude Egberink, Stoop and Poppe, 1988). This contribution discusses the approach which has been under development by the Dutch Road Safety Council for several years (Stoop 1989, RvV 1991.1). This method is, among others, based upon the experiences of the NTSB in the USA and the Dutch Admiralty Court (Stoop 1991.1).

1.2 A systematic approach
The in-depth analysis of road traffic accidents has produced varying results. Researchers often based their approach on the assumption that as much data as possible had to be acquired on the spot. This was to be done by a multidisciplinary team as soon as possible after the accident and before traces were wiped out. Following the principle that every accident is a unique phenomenon, researchers in road traffic safety have expressed their scepticism about the wisdom of such in-depth research and also about generalizing over the deductions from such research.
The current approach rejects this 'as soon as possible on the spot method'. Instead of a multidisciplinary team, one researcher performs a preliminary analysis and reports to the Council, which decides whether or not there will be a Hearing and accordingly, resulting recommendations (Stoop 1991.2). The researcher does not try to get to the accident location as soon as possible but bases his preliminary analysis on the data collected by the police and well-informed local experts. This preliminary analysis focuses attention on items which will be selected for further research. The accident is reconstructed in detail and the accident sequence is revealed step by step, until a satisfactory explanation of the accident causation is achieved. Using a 'top-down' systems approach, a research strategy is applied in which it is possible to assume an underlying structure and to establish interrelations and patterns between the various findings (Stoop 1990). Application of a 'bottom-up' reconstruction produces a systems model of the accident, which clarifies the possibilities for preventive action. Such in-depth analysis not only concentrates on the behaviour of the operator in practice but also takes into consideration the design of the infrastructure and the vehicles, involves systems management, legislative authorities and the organization of rescue and emergency services.

2. Priority setting

It is not desirable to analyze every accident in-depth. Over and above the practical objection to the high costs involved in the investigation of the total number of accidents, a fundamental issue has arisen concerning the lack of selection criteria. If lessons are to be learned and similar accidents are to be prevented, the similarity between accidents has to be defined, leading to a typology which is capable of in-depth analysis. Accidents which can be so categorised are basically of two different types. Firstly, on the one hand, police officers, road-management and vehicle experts, by their experiences with large numbers of small accidents, make their own categorisation of accidents, related to the road infrastructure or to vehicle characteristics. On the other hand a characterization can be derived from statistical analysis of aggregated accident data which
lead to correlation patterns. It is an unanswered question as to how such categories or correlation patterns can be transformed into an accident typology which is open to in-depth analysis (Stoop 1989). Secondly, major road traffic accidents with a low frequency, occurring on highways during rush hours, in rain or heavy fog, often result in many casualties and considerable damage. Such accidents are by their nature unacceptable, as are airline and shipping disasters but they can be subjected to in-depth analysis. As a practical start, a major road traffic accident on the A 16 highway near Breda in November 1990 was selected for this type of analysis.

3. Analysis

In the analysis several techniques were applied simultaneously in order to optimize the collection of data and to achieve a satisfactory explanation of the accident causation. The research findings were formulated in a Preliminary report as a basis for a Hearing, organised by the Dutch Road Safety Council. Finally, the Council published Recommendations (RvV 1991.2). These techniques comprised:
- analyzing the accident reports of the police, including witness statements, the technical examination of the vehicles and detailed laboratory investigations
- interviews with experts from the fire brigade, medical rescue teams, road management, highway traffic control and highway patrol services
- accident pattern recognition of prevailing accidents
- driver task analysis, traffic flow and road image analysis
- on the spot investigation.

3.1 The Breda disaster

On the morning of November 6, 1992 the radio traffic information service announced fog in several regions. At the time, only a light haze had been spotted in the Breda area. In the early morning thick fog sprang up west of Breda and drifted eastward. Between 9.00 and 9.15 the fog crossed the western carriageway of the A 16
CONVECTION

EASTERN WIND

BREDA

BUILDED AREA

3.4 m

A - 16

~1.75 m

REFLUX

CROSS - SECTION A - 16
highway. Drivers approaching from Rotterdam were completely surprised by the thickness of the fog or did not notice it at all. In a number of cases this led to panic reactions with emergency stops, while oncoming cars were able to come to a halt in time. Several cars were able to proceed on their way afterwards. The first collision occurred between 9.15 and 9.17, followed by a considerable number of collisions. Although some vehicles were able to stop in time, they were pushed into the collision by others, coming in from behind. Heavy trucks in particular contributed to the chaos. Three people were killed, several injured and 56 cars were involved. Shortly after the first collisions, more collisions occurred on the eastern carriageway, from the direction of Antwerp. As before, some drivers were able to stop in time, but were pushed into preceding vehicles. This collision resulted in 5 people being killed and several injured. 45 cars were involved. A number of cars were set on fire. In total, there were 8 deaths and 27 injuries, of which 11 were serious.

3.2 Background factors

The fog
Fog normally originates in the landscape after cold nights under optimum local meteorological conditions. The development of fog requires a slight gradient in the scenery, the presence of open water and a slight wind. At Breda, the fog was able to develop because in addition to the prevailing eastern wind in the upper layers, there was a minor reflux in a westerly direction, due to the thermal convection over the city, close to the accident location. The moist, saturated air was thus transported to the lowest point in the landscape where it condensed to a heavy fog. The fog was trapped on the highway between a sound barrier east of the highway and two adjacent flyovers to the north and south of the accident location.

This reflux hypothesis could be confirmed by a photograph, accidentally taken from a plane over the location.
TRAFFIC AREA BREDA

fig. 2

Hollands Diep
Moerdijk
Knooppunt Zonzeel
Dordrecht Rotterdam

Knooppunt Terheijden
Terheijden

Prinsenbeek

Knooppunt Prinsenbeek

Etten-Leur

Knooppunt Terheijden

Knooppunt Rijsbergen

Knooppunt Galder

Rijsbergen

Antwerpen

BREDA
accident location

N58

N263

A16

A27

A58

A59

TRAFFIC AREA BREDA
The road

The A16 highway is a part of the international transportation routes between Rotterdam and Antwerp and between Flushing and Germany. There is intensive regional traffic and by the discouragement policy of the local authorities, much urban traffic pulls off to the highway network around the city.

Traffic intensity varies between 65,000 and 70,000 vehicles of which about 25% comprises heavy freight carriers. Due to the many junctions and acceleration lanes, the traffic situation is very complex and at rush hours, congestion is a common phenomenon.

fig 2

The accident location is not considered a black spot, compared to other parts of the network. The road management considers the location as improved, compared to the situation before reconstruction. Road image analysis indicates that situations elsewhere in the network are worse (Stoffelsen 1991). The conclusion was that the road was not fit for the present use.

The road user

Under normal conditions, the task of a road user on a highway is relatively simple. Encounters with other users follow simple, predictable patterns. The road user is able to anticipate situations. In traffic flows with high intensity, the road user is not or does not feel himself free to select his own speed and following distance. These parameters are forced on him by the traffic flow. Such conditions do not provide a safe environment and the driver himself does not perceive such a situation as safe. This was verified from several witness reports. Aggravated conditions may cause unsafe deviations in the already unstable traffic flow. Fog is such a condition. Fog causes a switch from the 'anticipating behaviour' into 'direct following' behaviour. Such 'direct following' requires an increased mental effort and is more susceptible to error. Considerable differences occur in individual skills and experience and inadequate response behaviour may arise.

At the accident location an additional task was added to those obtaining a normal anticipation behaviour. Passing the flyover, the drivers had to deal with lane shifting.
and with traffic joining in from several junctions, each selecting their own speed and direction in a saturated traffic flow. A sideways anticipation was added to the forwards anticipation. The official reports clearly state that many drivers were fully occupied with these tasks and did not notice the fog at all. Forward vision was obscured by the sun, shining into the faces of the drivers.

The vehicles
During the technical examination no defects were found which might have led to the accident. To obtain a preliminary insight into vehicle characteristics, interviews with experts were held and revealed several items of interest. Training courses for professional freight truck drivers did not include requirements with respect to vision capability, vehicle control or handling, nor knowledge about vehicle and cargo dynamics. Major changes have occurred in vehicle technology without adequate training in how to handle the truck in case of emergency. Turbochargers, electronic power shift, cruise control, cabin comfort, improved seats and ABS have created a new generation of freight trucks. These new trucks have a reduced visual and tactile feedback to their drivers and do not match their trailers, which have different braking characteristics. New management systems like 'Just in Time' and fierce competition put a heavy pressure on the drivers to maintain their time schedules. Finally, rescue from modern trucks and private vehicles has become more difficult due to the modern safety devices that are installed. The vehicles are less accessible because of the jamming of deformed reinforced structures, impenetrable windshields and the blocking of failed electrical doorlocks. Short-circuiting of the electrical wiring and hot spots on the engine during the crash prove to be frequent causes of fire.

Regulations
The Netherlands has limited regulations with respect to the admittance to motorways of certain types of transport during increased risk situations such as storm. There are neither rules for traffic stream control, nor are there speed limitations on the network segment where the accident occurred. There are no legal
obligations for the separation of personal and freight vehicles, no speed limitation devices inside freight trucks, neither are there driving prohibitions during adverse weather and vision conditions.

3.3 Accident causation

In conclusion, the Council decided, after a Hearing, that the accident was caused by a combination of several factors. The A 16 is a dual carriage highway with a high vehicle intensity and a complex traffic pattern, which easily leads to disruptions of the traffic flow. On November 6, a limited area of very dense fog suddenly blocked the road, causing a variety of reactions among the drivers. The speed differences on the West carriage way caused a shockwave in the traffic flow, which was the direct cause of the collision. The collision on the East carriage way was probably initiated by the collision on the West lane due to the fog and by the sound of the braking and colliding vehicles. The severity of the accident was to a major extent caused by the contribution of heavy freight trucks and the fire that broke out among the closely packed vehicles. The rescue and fire fighting was carried out in a proper way, despite the shortcomings in coordination and communication and the problems in gaining access to the location.

Recommendations
The Council therefore concluded that recommendations should be made with respect to a number of aspects which had contributed to the accident (RvV 1991.2). With respect to the fog an inventory of vulnerable areas should be made and fog detection systems installed. Radio traffic information should be more precise, by giving a fair indication with respect to locations and sight distances thus enabling transport companies to make decisions as to whether or not they should dispatch vehicles into areas where aggravated weather conditions obtain.

The roads should be adjusted to the traffic flow demands by reconstruction of the infrastructure, support by automated traffic signalling systems.

With the aim of reducing the extent of the accident area, an effective protection system for the tail of the
accident is necessary. A linking between the traffic flow signalizing of the two carriageways should be introduced. With regard to the reduction in the severity of accidents, a transportation disaster management scheme should be drawn up. Such a scheme should incorporate a clearly defined command structure, emergency accesses to the road, integrated alarm stations and better coordination between communication channels. Vehicles should be equipped with fire extinguishing units and speed limitation devices and freight trucks in particular should be equipped with improved collision deformation zones.

4. Background developments
Since the in-depth analysis is based on a systems approach, the focus of attention is not only the systems level of the driver in his interaction with the road, his vehicle and with other road-users, but also on higher systems. The analysis of the accident revealed accident causation factors at other levels of the system.

With regard to road design:
- a lack of safety principles in road design was found. Concepts such as fail-safe/safe-life, crash worthiness and damage tolerance were not applied. Similar safety-related design techniques already widely applied in aviation and shipping were not implemented neither were experiences from abroad taken into account. The highway system proved to be vulnerable to accidents and once an accident had happened, damage control was hindered due to the lack of equipment available on site. Access for rescue and police services to and from the location was poor and assistance to surviving drivers and passengers had to be given from a nearby hotel
- the dual-function principle of the network was found to be questionable. The main infrastructure in The Netherlands is used as a relief for high traffic intensity on lower networks, causing a complex mixture of traffic with different destination, vehicles, cargos, experience and attitude. This duality requires many junctions, creates fluctuations in the network and generates a disorderly traffic flow image. A mixture of many types of vehicles occurs, without any limitations
With regard to their admittance to the network, local factors were not taken into account. The Breda area is known to be sensitive to the outbreak of fog. No measures were taken although fog-related accidents had already happened in the network. It required the occurrence of the accident to stimulate the introduction of a test unit for fog detection in the area and to implement a traffic-flow signalling system. Similar local factors exist in other parts of The Netherlands (See fig 3). With a planned increase in the traffic intensity on highways in fog sensitive regions, similar accidents may occur more frequently in the near future. Preventive measures should be taken particularly where major infrastructural projects are planned and where highways are incorporated in transportation corridors. No safety impact studies were undertaken, no accident casuistics were performed during the reconstruction of the road, although the adjacent segments were known to be questionable with regard to accidents. The maintenance of the road was subjected to the priorities of higher road authorities, which favoured wear and repair over safety devices and denied the requests of the local road management for traffic flow management systems. 

With regard to vehicle design, it was found that:

- prevention of damage to car occupants was restricted to the absorption of kinetic energy during the crash. The emphasis on kinetic energy absorption caused the occupants to be caught in a deformed reinforced structure, with unbreakable windshields and blocked doorlocks. There were no circuit-breakers in the electrical system to prevent short circuiting as a cause of fire. Fire extinguishing equipment was of unsufficient capacity and supply and the proportion of incombustible materials used in the vehicles was low

- vehicle dynamics was problematic. The mismatch between the braking characteristics of trucks and
fig. 3

Global indication fog-related areas
their trailers, between personal vehicles and freight trucks, caused a wide variety of braking behaviour. Due to the improvements in vehicle comfort, a diminished tactile feedback led to misjudgment by drivers of the actual speed and outside situation. Finally, cargo can be very dangerous if it breaks out of the containment. This situation causes severe hazards for the driver and for other road users because of the unstable behaviour of the vehicle and because of the large masses involved.

With regard to regulations:
- there are no codes of conduct for correct or 'normative' behaviour for driving in fog, resulting in a large variety of behaviour. In the driver licence training, no attention is paid to driving in fog, neither is training given in how to behave in deviant conditions nor in how to control a vehicle in emergency situations.
- there are no regulations with regard to: limiting heavy freight trucks to the right lane only, prohibiting heavy freight trucks from overtaking other vehicles, mingling of trucks and personal vehicles in one lane, limited access to the network in case of aggravated conditions such as storm, snow, or fog.
- the organization of the rescue and firefighting, police and medical assistance should be improved. Regardless of the efforts at the location itself, several lessons had to be learned with respect to command structure, communications and coordination between the major rescue services.
- last but not least, the current regulations with regard to speed and following distance are contradictory to traffic stream theory. Already in 1934, Greenshields developed his empirical Basic Traffic Stream Modes, in which a relation was established between speed, flow and density of vehicles in a traffic stream (Greenshields 1934). According to Greenshields, individual drivers have to adjust to the speed and distance of the flow if the intensity increases. At the point of maximum intensity the flow becomes unstable and if a slight disruption occurs, such as a braking manoeuvre in...
BASIC TRAFFIC STREAM MODE

Parabolic speed-flow relationship

Parabolic flow-density relationship
fog, congestion will take place. Such speed and following constraints are not taken into account in conjunction with current legislation.

5. Conclusions

Conclusions can be drawn from the case study in two respects. First, in the application of in-depth analysis a wide variety of techniques can be applied, dependent on the problem definition (Oude Egberink and Lourens 1991, Stoop 1991.2). In the iterative process towards a satisfactory explanation of the accident, the standard information of police reports proved to be of invaluable importance. This information provides the basis for further research. In later phases of the step by step approach, other techniques could be applied, such as expert consultancy, on-the-spot investigation, traffic flow theory, road image and task analysis. A detailed reconstruction and satisfactory explanation of the accident could be achieved.

Secondly, the application of a systems approach revealed the importance of higher systems orders. The design of vehicles and roads, the lack of regulations, training of and information to drivers with respect to driving in fog, clarified a more general pattern in this type of accident causation which remains invisible in a statistical or juridical approach to accident analysis. The use of a systems approach however, demonstrated predictive potential. It clarified a possible future trend in major highway accidents. Combining high intensity roads and a landscape, where fog frequently occurs, may introduce a new type of accident: the highway disaster. The introduction of transportation corridors, where various modes of transportation are combined into one restricted area, is a vulnerable concept with respect to major accidents and mutual interference of modes. Without an integrated design concept, where accident causation is foreseen and dealt with, more accidents of this type are inevitable in the near future.
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A BLACK-SPOT APPROACH FOR A PROVINCIAL ROAD NETWORK

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Abstract

In the Netherlands in the eighties the improvement of black-spots was increasingly dealt with systematically by means of a black-spot manual (in Dutch: AVOC manual). This methodology includes four stages: selection, analysis together with a study of the locations, proposals for measures and setting up priorities. Usually no more than a few crossings are analyzed simultaneously. As an exception to this rule, HASKONING studied much larger numbers simultaneously in the provinces of Limburg and Noord-Brabant: 36 and 21. These studies included road sections of sometimes dozens of kilometres, as well as single crossings. For Limburg the study has been limited to a relatively summary elaboration of the measures to be taken, with the intention to draw up an indication of the costs for setting up of priorities. Part of the measures to be taken was executed directly, such as installing signs advising motorists to switch on their lights. For situations within the 30-mile zone, no confrontation with other aspects has taken place, which might have influenced the measure.

The analysis in Noord-Brabant differs from the one carried out in Limburg, to the extent that measures were taken recently at a number of locations. A further difference is that the measures have been elaborated in a fairly detailed manner, so that the estimate of the costs has become less general.

Cost effectiveness is the basis for the order of priorities. In Limburg crossings and road sections have been assessed in terms of effectiveness as two separate groups. Consequently, the order has been drawn up, the situation with the highest effectiveness being listed first. In doing so, accidents are included in the assessment in terms of value: death and/or injury being 10 times as important as damage. In Noord-Brabant no cost effectiveness has been drawn up.

Finally, it may be mentioned that the road maintenance authority in Limburg has included the measures in a long-range programme for the entire province, whereas Noord-Brabant intends to carry out the measures for each region as quickly as possible.

1. Introduction and indication

In 1979 the AVOC Manual (Policy for Road Accidents at
Localities with the Highest Concentration of Accidents) was published. Usually only a few crossings (3 to 5) of the road maintenance authority are analyzed by means of this manual. It is therefore exceptional that HASKONING has carried out two analyses on far more extensive numbers in the last few years: 36 and 21 situations respectively. Since the methodology had to be adapted slightly, this has been the reason for including it as a contribution to this conference.

In section 1 the AVOC annual will be briefly discussed, whereas sections 2 and 3 provide details of both projects. In section 4 a comparison is made between the more general AVOC studies and these two large-scale projects. Section 5 discusses the setting up of priorities and in section 6 it will be shown how the road maintenance authority has implemented the findings of the study. Section 7 will round off with a conclusion.

2. Survey of the AVOC methodology

Broadly speaking, the AVOC methodology consists of determining the dominant features of registered accidents, and, by means of these features, to examine whether the reason for these accidents can be related to the design or the situation of a crossing. The various stages of the methodology are mentioned in the schema below.

AVOC-METHODOLOGY IN STEPS

- Pattern of Accidents
- Features Accidents
  - Dominant Features
  - Possible Reasons
  - Technical Aspects
- Behavior Road Users
- Examination Crossing
- Measures
  - Cost Effectiveness

Inventory: Location and Traffic Data
The first part of the methodology is the inventory of location and traffic data, like the function of feeder roads among other things. Next, the pattern of accidents is charted, the accidents being indicated in a drawing of the present situation by means of a standard coding system. The features of the accidents are then categorized in such a way that the dominant features will come to the fore. Guidelines for determining widespread dominant features have been drawn up by now. At this stage national data are also used. Subsequently, assumptions are drawn up about the possible reasons for the accidents. They may relate to the behaviour of road users, as well as to technical aspects, such as defaults in the design or flow of traffic. The study now centres on the crossing concerned. It is examined systematically whether the expected defaults are present indeed. If this turns out to be the case, measures can next be drawn up. For each (group of) measure(s) the expected decrease in the number of road accidents is also assessed. Subsequently, it is possible to determine the cost effectiveness on the basis of the investment and maintenance costs.

3. Information about both projects

The Netherlands are divided into twelve provinces. The provinces of Limburg and Noord-Brabant make up the southern part of the country. Limburg is elongated, and is situated along the river Maas from Maastricht to the vicinity of Nijmegen. Limburg shares long borders with Germany and Belgium. Limburg lies east of Noord-Brabant, which is called "North" because neighbourly Belgium has a province of Brabant as well. Noord-Brabant extends in southerly direction towards the delta area of the North Sea: the province of Zeeland.
The national motorways in the Netherlands are built and maintained by the Ministry of Transport and Communications, which has developed an organization for this purpose, bearing the name of the Department of Public Works (Rijkswaterstaat - RWS). RWS has existed for centuries, which has resulted among other things in roads being maintained which lead through villages and towns. Therefore RWS has to deal with safety problems in urban situations, as well as on interurban roads and motorways. RWS has provincial departments being responsible for their region. The projects described here are commissioned by RWS Limburg and RWS Noord-Brabant.

The project in the province of Limburg was carried out in 1988 and included a total of 36 black-spots, 16 of which are crossings and 20 of which are road sections. Of the sections 9 are situated within the 30-mile zone, and 11 outside it on an interurban road. RWS itself collected the data of the accidents and included the black-spots in a working list. This way the first stage of the AVOC methodology was started: selection, and a survey was made with the situation of most accidents being listed first. At the crossings the number of accidents varied from 16 to 109 accidents for the years '83, '84 and '85. If a value of 10 is applied to each fatal accident or injury, these figures become 48 and 225 respectively. For the road sections this figures are between 54 and 251 for each kilometre of the road. These are reasonably large numbers which result in fairly long periods of analysis. The usual AVOC methodology is used in the analysis: searching for the dominant accidents, setting up hypotheses, studying the location, drawing up measures and determining costs and effectiveness.
The selection has been computerized as much as possible by processing the manoeuvre diagrams by means of an AutoCad programme, and by lubricating the data of the accidents by means of the PC. A comparison has been made with national figures. It turned out from this comparison among other things that accidents take place more than averagely on crossings when the surface of the road is wet: 34.0 % against 30.2 % nationally; the crossings were substantially better after dark in comparison with the national figure: 20.2 % versus 27.6 %. This latter also applies to the Limburg road sections, which also scored better in the case of a wet surface of the road.

It may be obvious that the location study had to be planned rigidly. A team of two staff members has been continuously on the road. In advance it was carefully investigated what the most efficient order would be, taking into account the results of the first stage of the analysis. Consequently, in such cases, special hours or days of the week were kept and if possible weather conditions were taken into account too.

The measures are mainly described and indicated summarily on maps of the situation. As a result, the costs have also been determined only generally. In doing so, use has been made of standard amounts and none of the measures have been budgeted separately. Naturally, this is no objection for the purpose of a mutual comparison. Within the 30-mile zones, no measures are drawn up or considered focusing on other aspects, such as circulation, the environment or barrier effect. On the basis of consultations with police officials, it has been stated as a matter of standard that accidents occurring when traffic light are working are the result of traffic users "jumping the lights". Aside from the usual material road measures, this study has also paid attention to other aspects, such as extra police control of visibility of cyclists and mopeds and their adequate use of lights, or setting up signs, recommending motorists to "SWITCH ON LIGHTS DURING DAY-TIME", alongside roads lined with many trees.

In Noord-Brabant the selection was also made by RWS on the basis of the figures of accidents for '86 and '87; again by applying values of 10:10:1 for fatal accidents, injuries and damage. The study was carried out in 1989, in which the surveys of the accidents over several years were made dependent on the previous history of the location. All in all, the study includes 21 crossings divided over 18 locations. The number of accidents is between 53 and 219 for a period of 3 or 4 years. The majority of locations consists of crossings in motorways and connections of sliproads of motorways to the lower road network.

The previous history of the locations is the reason for dividing up the study in three parts. First there are situations for which an AVOC study was carried out a few
years earlier, largely followed by measures. Evaluation is therefore possible. Secondly, there are situations for which measures have been drawn up for different reasons. The question remains to which extent they will improve the safety. A limited AVOC analysis was carried out for these locations. Thirdly, there are situations to which the usual AVOC analysis applies.

Starting with this last group, it can be stated that naturally the AVOC methodology has been followed. A noteworthy detail may be that the situations have been extensively photographed, that the measures have been investigated in much greater detail and have been budgeted more carefully as a result. The reason for this latter is that the further responsibility of the projects lies with the regional departments of the provincial RWS. In one of these cases, it was decided during the project to include in the analysis an adjacent lane with crossings. This is the only stretch of road in the study, which is moreover within the 30-mile zone.

The second group with this limited approach consists of five locations. With two locations the AVOC analysis has resulted in similar measures although for different reasons; naturally, the analysis has added a few specific safety measures. With regard to the other locations, traffic lights had been planned or considered. It turns out that for safety reasons this is unnecessary, although in two instances a safety proposal has resulted in lower capacity, so that traffic lights have been made necessary again.

Six locations fall within the first group: evaluation. The method consisted of a comparison of the first analysis with the accidents having occurred, and afterwards of a possible addition of measures to fight against the remaining types of accidents. The general conclusion may be that safety has been increased, unless the measure has not (yet) been carried out. The remaining accidents are mainly due to bad flow, so that only structural measures will help (two-level crossings) and/or regular optimization of the measures. For this group, the measures have been elaborated and budgeted in great detail as well. This does not only have consequences for the number of activities, but also for the working process and the contacts with the officials of RWS. In the next section a few interesting locations from both studies will be indicated, whereas subsequently the differences with a "common" AVOC study will be discussed.

4. A few interesting locations

As an illustration of the study in Limburg we will mention the situation of a single-lane national road through a small town centre, called Reuver. It concerns a road here of 1.6 kilometres. At the crossings accidents with cyclists and mopeds turned out to be dominant. This was attributed
to the lack of clearly indicated facilities for crossing the road. With regard to road sections, cycle and moped accidents were also dominant. Alongside the road there are a number of different kind of cycling facilities: adjacent and separate, always combined with parking lanes or permission for parking. It turned out in this case that both kinds of cycling facilities resulted in a deviant accident pattern. On the separate bicycle lane hardly no accidents with mopeds occurred; on the adjacent lanes they occurred quite frequently. In order to improve the situation, the adjacent lane should have to be replaced with a separate bicycle lane. However, this clashed with the other aspect, that is to say, with parking. This meant that RWS, being the road maintenance authority, first had to discuss this with the local council to investigate whether it was possible to organize parking differently, before safety measures could be taken.

In Noord-Brabant it showed from the evaluation studies that at the crossings in the traffic-lodden national roads between Nijmegen and 's-Hertogenbosch, and between 's-Hertogenbosch and Eindhoven, a considerable increase of traffic safety had been achieved, by consequently adapting the form of the crossing and traffic regulations, according to the existing guidelines. The kind of measures which had been effective could be indicated in the evaluation study especially. In general the renewal of the automatic traffic regulation system worked positively, so that the amount of traffic could be anticipated. The improved maintenance (roughness, drainage) also turned out to be effective. It was remarkable that at a crossing at which the old regulation system had been maintained, the picture of the accidents had become more unfavourable. It was a case of a high increase of the number of accidents, as well as the number of cases of injuries. Apart from that, it turns out that the national roads concerned have reached their maximum in terms of capacity, so that a further improvement of traffic flows (which might increase safety on the national roads) might lead to secret traffic on parallel routes through the country area. On balance, the safety of the entire area around the national roads might eventually become negative. Other than in the case of a "common" AVOC study, conclusions could be drawn, because of the broader basic organization, relating to characteristics which were present at all crossings for example, or relating to the function of a lane for the adjacent built-up area. Especially in the case of road sections merging through-traffic with local traffic this provided extra possibilities for analysis.

The method may be characterized as a first development towards a regionalized way of dealing with the lack of safety in the Netherlands.
5. Setting up priorities

On the one hand it says in the AVOC manual that the road maintenance authority is free to determine in its own way what the order for executing the proposed measures will be; on the other hand it presents a method on the basis of cost effectiveness. The other criteria may be: locations with the largest number of casualties, locations with cycling accidents, or the improvement of the greatest number of locations on a budget determined in advance.

With cost effectiveness the construction costs are turned into a yearly amount and increased by the yearly maintenance costs. Apart from this it is assumed that the proposed measures will do away with all the accidents concerned: the accidents saved annually. Costs divided by accidents produces the amount necessary to prevent one accident from occurring: the cost effectiveness. In the manual it has been decided to put the locations with the lowest figure at the top of the list, because in that case the profit on the investment is highest.

COSTS-EFFECTIVENESS

COSTS: construction costs (per year) + maintenance costs (per year) = total costs (C)

ACCIDENTS: number prevented accidents (p.y.) (A)

EFFECTIVENESS: \[ E = \frac{C}{A} \text{ (dutch guilders)} \]

in Noord Brabant: min. E: f23.- max. E: f2.330.-

This often results in the location with the highest number of accidents not being at the top of the list any more. This was also the case with the Limburg study. The five locations with the highest effectiveness initially were listed numbers 20, 23, 18, 16 and 26 in terms of number of accidents. The location with the highest number of accidents is listed as number 8. When there are more dominant accidents, there will also be put forward more packages of measures. These will have their own effectiveness, so that
in this survey one location may feature more than once. To be able to compare the lanes mutually, as well as with the crossings, the number of accidents have been converted to accidents per kilometre. This way the effectiveness survey has been set up on the basis of both types of location. With the financial data Limburg RWS can first determine the amount of money necessary for the entire safety programme, and secondly turn this and other matters into a long-range scheme. The large spreading of effectiveness is remarkable, ranging from \( f12,= \) for each accident prevented to \( f 14.19-0,= \) (guilders per year).

In Noord-Brabant it ranges from \( f 23,= \) to \( f 2.330,= \). In this case the order also changes. In terms of evaluation the location with the largest number of accidents is now listed in second place. With the group of locations having used AVOC for the first time, the location with the highest number of accidents ends up in third place with one package, and in place eight with another package. The differences are less substantial, yet they are present nevertheless. With the financial data presented, the management of RWS Noord-Brabant, as well as those responsible in the regional office, can reserve total amounts as well as setting up long-range planning.

6. RWS's opinion of the results

Both studies were also intended to bring the approach towards the lack of safety to the attention of the regions directly involved. This is considered to have been successful. For Noord-Brabant this has also been a proper means of introducing computer programmes for following and evaluating the lack of safety in the regions. The studies also include sufficient points of departure to be able to achieve the implementation of measures in consultation with other road maintenance authorities. The accident studies have now become part of the procedure for intended road reconstructions, which is experienced as a positive result. The results of the AVOC studies have in some instances led to a faster approach.

7. Conclusion

It has turned out to be possible to also apply the AVOC methodology in order to compare larger numbers of location with a high concentration of accidents, as well as to insert road sections and crossings in one list of priorities. In those towns in which the local council ultimately chooses by means of the AVOC analysis, the management of a department may use the result as an underpinning of the financial long-range planning.
Another result, not intended, is the finding, on the basis of the evaluation of previously analyzed locations, that the proposed measures have achieved their intended aim. As a result, the usefulness of the AVOC methodology and the AVOC manual is emphasized.

The AVOC focuses on locations with high concentrations of accidents, so that relatively many accidents have not yet been analyzed. The last few years the need has come into being to deal with regions and routes because of reasons mentioned above, yet also because the local population has been more outspoken about what it considers a dangerous route or a dangerous district or area. Within the Ministry of Transport and Communications a manual for routes and areas is presently put together, as well as a methodology with which accidents with a particular characteristic can be selected and analyzed: for instance young casualties, or casualties due to crossing the road, or those happening in bad weather conditions. The intention is to present this new manual, in which AVOC has been included integrally, early 1993.

**ANALYSIS DANGEROUS SITUATIONS**

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  SELECTION
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AGEB  AVOC  ASPE
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  PRIORITY
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EVALUATION
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A PROTOTYPE EXPERT SYSTEM FOR RECONSTRUCTING PLANAR TWO-CAR COLLISION ACCIDENTS

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A Prototype Expert System for Reconstructing Planar Two-Car Collision Accidents

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ABSTRACT

The purpose of accident reconstruction is to identify the pre-impact behavior, and to portray the entire process, of collisions, which are essential to the liability assessment and cause analysis of accidents. The credibility of reconstruction results relies heavily on experts' knowledge and skills in performing the task, with the constraints of available at-scene data. Nevertheless, the scarcity of real experts and, often, time constraints have made the reconstruction task even more difficult than expected. This is particularly true in Taiwan, even the so-called multi-disciplinary Accident Liability Assessment Committees are formed, at terms, by government officials and scholars in somewhat related fields.

For solving the above problems, research is being conducted to establish an expert system for accident reconstruction. The unique features of this system include reproduction of accident scene, a knowledge base, and a complete inverse/simulation model. The reproduction of an accident's scene employs image processing technique to transfer all the images on the photograph, or ultimately from a video, to the computer screen. The internal coordinates and the relative spacing of the images are thus
created, on the screen, and proportioned to the real accident's scene.

The knowledge base of the expert system includes facts and rules, which are formed by interviewing experts, studying accident cases and compiling references on accident reconstruction. The facts are the descriptions of static at-scene data, while the rules describe relationships between pre-impact behavior and at-scene data and also involve the establishment of inference procedures for efficient accident reconstruction.

The complete inverse/simulation model of car-to-car collisions consists of two parts. One is called the "inverse" method, which is to inverse the at-scene data, together with those inferred from the knowledge base, to get the pre-impact speed, by using reasonable motion and momentum equations. The other, called the "trial and error" method, uses as input the initial velocity thus obtained, with other relevant data, to portray the whole process of collision by animation. Furthermore, the operation of the system is an iterative one if the reconstruction results deem to do so; this is illustrated through a case study of the well-known RICSAC experiments.
I. INTRODUCTION

The purpose of accident reconstruction is to reasonably identify the pre-impact behavior of vehicles involved and portray the process of collision. Nevertheless, accident reconstruction is a very complex task which needs multidisciplinary professional knowledge and skills. The sources of data required for accident reconstruction include police accident reports, an at-scene investigation, a inspection of vehicle deformations, a driver and/or witness statements, and so on. These data are used by reconstructionists to analyze and reveal the process of collision. Based on the knowledge about physics, mechanics, psychology, physiology, traffic engineering, etc.

Up to date, individuals involved in accident reconstruction have often encountered two major problems. The first is how to effectively obtain the entire at-scene data for accident reconstruction. This is to counteract the fact
that the collected at-scene data are usually insufficient, due to their diminishing nature or investigators' negligence. The second concerns with the scarcity of experts in accident reconstruction, particularly in less developed countries, such as Taiwan where the reconstruction work is done by a group of individuals from different disciplines. With most lacking professional expertise, compounded by the time limitations, the reconstruction groups have often found that the task is more difficult than expected. Therefore, the outcomes or conclusions of accident reconstruction, sometimes, are not very convincing, or even doubtful.

For solving the above problems, and upgrading the validity of reconstruction results, the research being conducted has been oriented towards two directions. One is to develop a method for the reproduction of accident's scene. The other is to establish an expert system for accident reconstruction. The following section reviews the general methods for non-graphical transformation and introduces a proposed technique, called image-processing transformation. The possibility of constructing an expert system for accident reconstruction is also discussed. The third section describes the compositions of the prototype expert system developed to date. The fourth section demonstrates the application of the expert system to a case study from the well-known RICSAC experiments. The final section summarizes some directions for future research.
II. THEORETICAL BACKGROUND

Reproduction of Accident Scene

Plane-to-plane transformation method The well-established equations describing the plane-to-plane transformation are [1, 2]:

\[ X = \frac{(A_1x + A_2y + A_3)}{(A_7x + A_8y + 1)} \]
\[ Y = \frac{(A_4x + A_5y + A_6)}{(A_7x + A_8y + 1)} \]

In the above equations, \( X \) and \( Y \) are coordinates of any point on either one of the planar surfaces (such as the photograph), and \( x \) and \( y \) are coordinates of the corresponding point on the other plane (such as the roadway). \( A_1 \) to \( A_8 \) are projection coefficients whose values are determined by at least four-points measured. This technique will work well, only provided the roadway surfaces is flat and the lens distortions, film non-planarity and other errors introduced in the exposing and printing process are not too great [3].

Camera reverse-projection method The camera reverse-projection method is based on reestablishing the original camera view-point and its picture-plane orientation. This can be accomplished by returning to the scene with a transparency of the photograph and viewing the scene through the transparency with an appropriate viewing device [4]. Because the physical reposition of the camera at
the scene may take a relatively long time, it is difficult to accomplish at scenes of heavy traffic [3].

**Analytical reverse-projection method** The analytical reverse-projection method is analogous to the camera reverse-projection method, but uses discretely surveyed scene points to mathematically determine the camera viewpoint and picture-plane pose [2]. The method is based on the fact that once the original position of the camera lens center to the picture-plane (photograph), and the orientation of the photograph relative to the scene are all determined, then a vector passing from that established lens center point through any point of interest in the two-dimensional picture-plane defines the ray that passes through that same point of interest in the three-dimensional scene. The method requires no special photogrammetric equipment and can be implemented with the use of a personal computer [3].

**Two-image camera reverse-projection method** The two-image camera reverse-projection method utilizes the camera reverse-projection technique to find the intersection of two (or more) projected images from photos. The details of this procedure have been described by Woolley, et al [5]. The end result is the approximate location of selected points of vehicle damage in three-dimensional space.

**A proposed image-processing transformation method** The image-processing transformation method is based on two or more photographs, taken from different locations,
showing the same point of interest. It uses image-processing technique to determine, with calibration points, the real three-dimensional coordination of that point in the scene. Also for the insufficient or lost points, their images should be filled in or modified. Eventually, the location of the points in the picture (photograph) are transformed entirely to the actual three-dimensional scene. The method is still under development, yet to be formulated.

The Expert System Concept

Figure 1 illustrates the analogy between the operating process of an expert system and accident reconstruction system [6].

First, as in the expert system, the accident reconstruction system must describe the problem from related data, including police accident report, inspection of car crashes, driver and witness statements, and so on (as input for the system). Such descriptions are saved in the reconstructionists' brain memory, through their senses such as eyes, ears, mouse, etc., which are equivalent to the user interface of the expert system. When sufficient data are collected, reconstructionists begin to puzzle out the process of accident, using his experiences about accidents and the results produced by collision models; this process resembles that the inference engine of the expert system uses it's knowledge base to analyze. Finally, the physical description of vehicles' colliding process is produced, which is
equivalent to the suggestion and explanation for users in the expert system. From the above, it can be concluded that the concept of an accident reconstruction system is much analogous to an expert system, thus the establishment of an expert system for accident reconstruction is quite feasible.

III. CONSTRUCTION OF EXPERT SYSTEM FOR ACCIDENT RECONSTRUCTION

Since, the conceptual framework of an expert system for accident reconstruction has been formed, the task that follows is how to accomplish the main operation system. Most of all, the source of accidents must be fully recognized, followed by realizing the advance relationship within the facts. Thus, constructing a complete system for accident reconstruction is almost in order. The following introduces the source of accidents (the base for reconstruction), the compositions of knowledge base, and the unique features of the expert system established for accident reconstruction.

The Source of Accidents

The safety of traffic is maintained by stable balance among the interactive factors of drivers, vehicles, and roadway and environment, the three major components of the roadway traffic system. Any breaking of the balance may, in cases, result in incidents or accidents. The system is then represented by different status, the static data on which become the major source for accident reconstruction.
The key point of accident reconstruction is to look for the relationship between the causation (causes) and at-scene data (results). Based on these causalities, several critical points, such as collision location, impact points, and so on, can be inferred. These data are essential for a complete collision inverse/simulation model to accomplish the reconstruction work.

Compositions of Knowledge Base

The knowledge that the system needs has been classified into two categories. One is the facts and the other is the rules. The so-called facts are the descriptions of static-scene data, such as vehicle deformations, crashes, oil, dirts, skidmarks, and so on. This is illustrated in the left hand portion of Table 1. As discussed previously, these facts are concluded, from information on drivers, vehicles, and roadway-environment.

The rules are the descriptions of relationships between pre-impact behavior and at-scene date (refer to the right hand portion of Table 1), and the establishment of the inference procedures. Because difference exists between individuals doing the reconstruction and various types of accidents, the inference procedures take different forms, and are also complex. Based on the above-mentioned operational process of an accident reconstruction system,
and the needs for reconstructing planar two-cars collisions, the inference procedures are set as those shown in Figure 2.

The first step is to exclude those accidents which are not of planar two-car collision type, and then to collect the entire at-scene data. Based on the driver statements, witness statements, and vehicle deformations, it is to determine the direction of driving. Matching with vehicle deformations, as well as realizing the seriousness of personal body injuries, etc, is to determine the type of accident. When the accident type is known, data such as crashes, oil, dusts, tiremarks, and so on, can be used to infer the location of collision. Thus, the spatial relationship between the final position of cars and the collision location, is defined, that is, the distance from the collision location to each car and the vehicle's heading angle. Then, it can exercise the collision inversing computer model, described in next section, to calculate the pre-impact velocity. If a minimum energy loss is obtained in the inverse process, then the pre-impact velocity is accepted; otherwise, the parameters, such as lock-up ratios, steering angles, coefficient of friction, etc., are modified, and the entire process is repeated.

Finally, the output pre-impact velocity must be reasonable, otherwise go back to the beginning and sequentially check the results or adjust the parameters of each unique step, until reasonable pre-impact velocities are obtained. These pre-impact velocities are input to a
acomplete simulation model to animate the process of collision.

The related knowledge has been from three sources. First is the experiences of experts in accident reconstruction. The second is the compilation of technical papers, reports, and publications about accident reconstruction [7-15]. The third is the conclusions reached on some accident cases studies.

Based on the properties of the knowledge structure, and the functions supplied by the construction tools of expert systems to represent these knowledge, the LEVEL 5 construction tool is selected. It's functions in representing knowledge as IF–THEN, and sequential rules for setting the objectives or conclusions priorities, satisfy the requirements of accident reconstruction.

**Unique Features of the System**

From the above descriptions, it is easy to see that the unique features of this system developed include the reproduction of accidents' scene, a complete reverse/simulation model, and a knowledge base.

The reproduction of an accident's scene The image-processing transformation method developed thus far uses only one photo and it can only do the tiremarks measurements. The process of tiremark reconstruction with
this method is, firstly, erecting markers at several points on a curved tiremark. The marker is a three-dimensional post, of fixed-length about 1 m. Then, use a camera to take a picture, with camera's plane being parallel to the surface of markers. Next, use a scanner to input the film negative, then an image for the picture will be present on the computer's screen, with the scale being proportioned to the image on the photograph. Based on the physical length known from the markers, also knowing the pixels length of the markers on the screen, the coefficients of transformation are obtained. By knowing the at-scene location coordinations of these setting markers, then fit a curve through these points using higher order polynomials. The final result is the reposition of the curve on the screen.

A complete inverse / simulation model The entire process of car-to-car collisions is usually divided into three phases. The first pre-impact phase describes the states of individual vehicles prior to collision. In the meantime, the vehicles are said to have initial velocities. The second phase is called impact phase, in which impact occurs between vehicles with resultant collapses or deformations on their bodies. The initial velocities become the separating velocities during the impact of very short duration. The vehicles after impact, i.e., traveling to their final positions with separating velocities of impact. Based on these descriptions a complete inverse/simulation model has been established within the system, as shown in Figure 3.
Firstly, by referring to the at-scene data and using the third-phase inverse model, formulated by Hess [9], it is to obtain the separating velocities and angular velocities. Then it uses the second-phase inverse model, formulated by Brach [15], to find out the initial velocities and angular velocities. Finally, the first-phase inverse model is employed to obtain vehicles' pre-impact behaviors.

A simulation model of pre-impact, impact, and post-impact phases has been developed for the system. By inputting the pre-impact velocities, thus obtained through those inverse models, and additional data and parameters associated with each phase, the simulation model is exercised to animate the process of collision.

The knowledge base Figure 4 is the structure of the established knowledge base, which has been discussed previously. This knowledge base has 198 rules, divided into four parts. First part is associated with the parameter adjustment of the 3rd-phase, the post-impact phase, model. These rules are used to infer those data required for input to the 3rd-phase kinematic model, including lock-up ratios, tire-stiffness coefficients, and steering angles; totaled 155 rules. Based on the intensity of tire stripe deformation, the tire lock-up ratio can be inferred, which has four classes: serious deformation, some deformation, insignificant deformation, and no deformation. The formulation derived by Hess is used to infer the tire stiffness coefficients, and
The steering angle is dependent on the alignment of roadway [9].

The second part is the parameter adjustment of the 2nd-phase model, totaled 11 rules before inputting to the 2nd-phase impact or inverse model. These parameters include restitution coefficient (e), equivalent friction coefficient (u), and a moment or rotational, restitution coefficient (em). According to the literature on collision experiments [10-15], the concluded rules can infer a range of the above coefficients for different accident types, such as rear-to-rear, rear-to-front, etc.

The third part is the parameter adjustment of the 1st-phase model for the pre-impact phase. The key point in this part is to find the collision location. Other parameters to be inferred include the driving direction, accident type, tiremarks identification and so on. There are a total of 25 rules in this part. Based on the vehicle behavior in collisions, the vehicle deformations are used to find out the direction of principal force and the center of collapse, and then to determine the plane of impact. The driving direction of each car is determined by matching car crashes, thus determining the accident type. The location of collision is determined by tiremarks on the roadway, such as collision scrubs, swerve skidmarks, crook skidmarks, skidmark ends, gaps in skidmark, scarings and so on. The distance from final locations of cars to the collision site, and the vehicle heading angles are thus determined. The results inferred is used as
input to the 3rd-phase inverse model or collision simulation model.

The fourth part is the parameter adjustment in the whole system. Based on the sensitivity results of these parameters, the direction and scale of parameter adjustment are determined, and the priority of adjustment set.

IV. A CASE STUDY

A case, RICSAC #8, has been selected, from the well-known RICSAC staged collision experiments, to demonstrate the reconstructing process using the established expert system, corporated with the complete inverse/simulation model. The collision process thus obtained has been compared to that of RICSAC #8. The items being compared include the separating velocities and angular velocities and the initial impact velocities.

By referring to the records of collision experiments [12,13, 14], and using the preceding inference procedures step by step, the data and related parameters have been obtained, which serve as input for the models. They are shown in Table 2. Note that some input items, e.g., tire lock-up ratios, are specified as in ranges.
First, the tire lock-up ratios, as input to the third-phase inverse model, have been selected as 0.01 (front right), 0.01 (front left), 0.2 (rear right), and 0.2 (rear left) for vehicle 1, and 0.01, 0.01, 0.2, and 0.2 for vehicle 2, respectively. The separating velocities thus obtained are compared with the actual measurements, as shown in Table 3. The mean errors of the estimated separating velocities, and angular velocities are 18.5% and 45%, respectively.

For the collision phase, the pre-impact velocities have been calculated by the 2nd phase inverse model. The initial velocities thus obtained are compared with the actual measurements, as shown in Table 4. It can be seen that the mean error of the estimated initial velocities is only 7.3%, but the kinetic energy loss, $Q=676$, is quite high. Thus, the adjustment of some parameters is deemed necessary.

Based on the sensitivity analysis of parameters, the relationship between the tire lock-up ratios and separating velocities is shown in Figure 5. Figure 6 shows the relationship between separating velocities and the $Q$ value. So it is clearly that the $Q$ value can be decreased by raising the tire lock-up ratios.
Round two:

Based on the above analysis, the tire lock-up ratios are increased by 0.1, an adjustment suggested by the system, thus becoming 0.11, 0.11, 0.3, and 0.3 for vehicle 1, and 0.11, 0.11, 0.3, and 0.3 for vehicle 2, respectively.

New separating velocities have been obtained from the 3rd-phase inverse model, and are compared with the actual measurements, as in Table 5. It can be seen that the mean error of estimated velocities declines from 38.5% to 27%, and angular velocities from 45% to 36.5%, respectively.

As for the pre-impact velocities, they are identically obtained by the 2nd-phase inverse model. Table 6 shows the comparison between the estimated velocities and the actual measurements. The mean error of the estimated initial velocities declines from 10% to 8.6% for vehicle 1, but rises from 4.6% to 10.7% for vehicle 2. Nevertheless, the kinetic energy loss, $Q=122$, is significantly reduced. Since the tire lock-up ratios can not be adjusted any more, and the initial velocities look reasonable, they are assumed to be determined. To accomplish the reconstruction task, the system then triggers the simulation model to animate the process of collision.

V. FURTHER STUDIES
From the above descriptions about the unique features of the established expert system for accident reconstruction, it is fair to say that only a prototype expert system has been constructed. Research is still underway to make the expert system more complete. The following list emphasizes some directions for further studies:

1. It is to develop, and to formulate in computer programs, a method for the three-dimensional reproduction of an accident's scene using the image-processing transformation technique.

2. So far, the knowledge base of the expert system is quite insufficient and needs continuously updating and modification. Ultimately, it should be designed as capable of self learning, to gradually have the knowledge enriched and enhanced for practical use.

3. In addition to the equations of conservation of momentum, the impact-phase inverse model should provide the option of using the conservation of energy method. Different and more cases of collision experiments should be involved in the validity testing on the expert system, using both methods.

4. Equally important is the development of a three-dimensional CAD portray of collisions, as well as how vehicle body deforms during the impact.
ACKNOWLEDGEMENT

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REFERENCES


### Table 1: Examples of Knowledge base

<table>
<thead>
<tr>
<th>FACTS</th>
<th>RELATIONSHIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRIVER</td>
<td>injury part, seriousness</td>
</tr>
<tr>
<td>VEHICLE</td>
<td>deformations: crash types, directions, locations; lock-up ratios, oil scatters; dust position</td>
</tr>
<tr>
<td>ROADWAY</td>
<td>skidmark formation, length, darkness; scrubmark formation, darkness, alignment; pavement status; traffic volume; weather condition</td>
</tr>
</tbody>
</table>

### Table 2: Data and Related Parameters Input for the Model

<table>
<thead>
<tr>
<th>Veh #1</th>
<th>Veh #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>front</td>
<td>rear</td>
</tr>
<tr>
<td>Tire lock-up ratios</td>
<td>LF, RF</td>
</tr>
<tr>
<td>Steering angles</td>
<td>0° - 0.11°</td>
</tr>
<tr>
<td>Tire stiffness coefficients</td>
<td>20°</td>
</tr>
<tr>
<td>Impact surface angles</td>
<td>87°</td>
</tr>
<tr>
<td>Impact relative angles</td>
<td>87°</td>
</tr>
<tr>
<td>Driving direction</td>
<td>177°</td>
</tr>
<tr>
<td>E: coeff. of restitution</td>
<td>0.1 &lt; E &lt; 0.475</td>
</tr>
<tr>
<td>Em: coeff. of restitution</td>
<td>1</td>
</tr>
<tr>
<td>U: friction coefficient</td>
<td>0.4 &lt; U &lt; 0.6</td>
</tr>
<tr>
<td>Coeff. of friction on roadway</td>
<td>0.87</td>
</tr>
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### Table 3 Inversed Separating Velocities Compared with Measurements - 1st Round

<table>
<thead>
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<th></th>
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<th>Veh #2</th>
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<tr>
<td></td>
<td>Vx</td>
<td>Vy</td>
</tr>
<tr>
<td>Inversed value</td>
<td>-6.67</td>
<td>5.83</td>
</tr>
<tr>
<td>Error</td>
<td>40%</td>
<td>31%</td>
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</table>

### Table 4 Inversed Initial Velocities Compared with Measurements during Impact - 1st Round

<table>
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<th>Veh #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inversed value</td>
<td>-27.46</td>
<td>31.92</td>
</tr>
<tr>
<td>Measurement</td>
<td>-30.51</td>
<td>30.51</td>
</tr>
<tr>
<td>Error</td>
<td>10%</td>
<td>4.6%</td>
</tr>
<tr>
<td>Q value</td>
<td>676</td>
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</table>

### Table 5 Inversed Separating Velocities Compared with Measurements - 2nd Round

<table>
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<tr>
<th></th>
<th>Veh #1</th>
<th>Veh #2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Vx</td>
<td>VY</td>
</tr>
<tr>
<td>Inversed value</td>
<td>-9.58</td>
<td>7.5</td>
</tr>
<tr>
<td>Error</td>
<td>18%</td>
<td>28%</td>
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</table>

### Table 6 Inversed Initial Velocities Compared with Measurements during Impact - 2nd Round

<table>
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<tr>
<th></th>
<th>Veh #1</th>
<th>Veh #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inversed value</td>
<td>-27.88</td>
<td>33.78</td>
</tr>
<tr>
<td>Measurement</td>
<td>-30.51</td>
<td>30.51</td>
</tr>
<tr>
<td>Error</td>
<td>8.8%</td>
<td>10.7%</td>
</tr>
<tr>
<td>Q value</td>
<td>122</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1 The Analogy Between the Operations of An Expert System and Accident Reconstruction
Excluded those problems unsolvable

Obtain at-scene data

Position of vehicle deformation, Direction of travel (driver statements, witness statements)

Driving direction

Debris sites & directions, dusts, oil, tiremarks, weather

Accident type (head-on, right angle...)

Collision location

Spatial relationship from final location of cars to collision location

Inverse the pre-impact velocity

Minimum energy loss?

Reasonable?

Pre-impact velocity determined

Simulate process of collision

Figure 2 Accident Reconstruction Inference Procedures

Pre-impact phase model → Impact phase model → Post-impact phase model

Pre-impact velocity → Initial velocity during impact → Separate velocity → Accidents' scene

inverse → inverse → inverse

1st-phase inverse model ← 2nd-phase inverse model ← 3rd-phase inverse model

Figure 3 A Complete Simulation Model
Exclude those problems unsolved

1st-phase parameter inference

2nd-phase parameter inference

3rd-phase parameter inference

Parameters modification

Accident type

Collision location

Distances from collision location to cars

Vehicle heading angles

Figure 4 Structure of Knowledge Base
Figure 5 Vehicle Separating Velocity vs. Lock-Up Ratio

Figure 6 Kinetic Energy Loss vs. Vehicle Separating Velocity
AUTOMATION AND THE FUTURE OF DRIVER BEHAVIOR 1)

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ABSTRACT

This paper sets out by identifying five plausible stages in the automation of the road traffic system, ranging from the introduction of part systems that support specific task components (navigation, collision avoidance) to full automation of roads and vehicles.

It is then attempted to predict how drivers will respond to each successive stage of automation, and how this will become manifest in driver behavior. On the basis of this the paper assesses the safety consequences of each separate stage of automation.

INTRODUCTION

Automation - the allocation of tasks and responsibilities to a machine - is a potential way out of situations that human actors are not, or no longer, capable of handling. When applied to the road traffic system automation promises to reduce congestion both because of its potential to provide more optimal routing and to reduce inter-vehicle spacing in the longitudinal (and possibly also the lateral) dimension. And because of the latter - its potential to control vehicle interactions both longitudinally and laterally - it also promises more safety than the present system could ever hope to achieve.

That automation will fulfill its promises is often taken for granted. It seems indeed self-evident that collision avoidance systems will avoid collisions, or that navigation support will save on mileage because it reduces excess driving due to non-optimal routing. However, there is by now sufficient evidence to expect that things will be somewhat more complicated, and that much of this is due to the user's tendency to respond to an automated system with behavioral changes that may actually be counterproductive to what automation should achieve. Thus, whenever parts of their task are automated users will start to look for a new behavioral equilibrium that suits their own purposes, and the effects of this process of adaptation may come as more

1) This paper is prepared from a more extensive report commissioned by the Netherlands Ministry of Transport and Public Works (Janssen, Wierda and van der Horst, 1992).
or less of a surprise to the system designer. Another aspect of automation that one should be aware of is that, like any other process of change, it probably creates new and qualitatively different problems per se. These may or may not be serious, but the point is that an effort is required to anticipate upon them before their seriousness can reasonably be judged. It is on the basis of these general insights, to which specific research findings will be added when appropriate, that we will consider the successive stages of automation of road traffic as they will likely evolve. First, the stages themselves must be identified and described.

STAGES IN THE AUTOMATION OF THE ROAD TRAFFIC SYSTEM

Several authors (Johnston et al., 1988, 1990; Shladover, 1989) have sketched scenarios for the progressive automation of the road traffic system over time. In the view of these authors technology push and societal demands will interact and converge to a succession of stages in which more of the driving task is taken over by automatons at each next stage. This will in particular apply to higher-order parts of the network, that is, to interurban connections. If this is taken into consideration, and if we decide upon a fairly coarse level of description rather than on a fine-grained analysis of which the details will be of doubtful validity, five stages seem sufficient to cover the continuum that ranges from the present-day system to full-fledged automation of major connections that may be foreseen sometime halfway the 21st century:

Stage 1. Introduction of separate part-systems, first for navigation support, to be followed by longitudinal (car-following) support.

Stage 2. Introduction of integrated support systems that coordinate the actions of the available partial support systems.

Stage 3. Extension of integrated systems with lateral support components, both with respect to traffic in adjacent lanes and the own vehicle per se.

Stage 4. Introduction of so-called dedicated lanes for vehicles to be subjected to automatic execution of almost the entire driving task.

Stage 5. Full-blown automation of all major connections.
BEHAVIORAL ADAPTATION AFTER AUTOMATION AND ITS CONSEQUENCES

Before dealing with each separate stage we will present an inventory of effects that, in a general sense, can be expected to occur after some part of a task that was formerly performed by humans has been subjected to automation. The inventory is derived both from the general literature on human-machine interaction (Bainbridge, 1982) as well as from specific results originating from driver behavior research (Evans, 1985, 1991; Wilde, 1988). The following elements may be distinguished, where reference is in particular to consequences automation may have for safety:

(1) Drivers will display somewhat overall riskier behavior after automation, that is, they tend to trade the increased safety that automation offers for higher mobility; this may include an increase in their exposure at the same (previous) cost of safety.

(2) Drivers' knowledge that they are guarded by the automaton leads to a decrease in their general level of alertness.

(3) Drivers lose the skills for performing those components of the driving task that are taken over by the automaton, so that they can no longer apply these skills in the remaining cases in which that would be required.

(4) Human error will not vanish after automation, but will shift to the design and maintenance of the automaton.

(5) Failure of the automaton will lead to more serious accidents than was formerly the case, that is, there will be a shift from accident frequency to accident severity.

(6) Because severity rather than frequency determines public concern (the so-called 'risk aversion' factor in societal risk analysis) an eventual improvement in safety will not be perceived for what it is, but rather for less.

(7) Drivers whose task is (partially) automatized will experience a shift from risks taken voluntarily to risks imposed unwillingly, with a consequent demand for even lower objective risk levels than might already have been achieved.

(8) Finally, the promises of increased safety and efficiency of the road traffic system will invite groups of drivers to take part in traffic who, for whatever reason, have stayed out of it thus far. By itself this will already increase exposure, and as such it is in fact another instance of the phenomenon that has already been mentioned under (1). In so far as these groups are composed of vulnerable or otherwise high-risk members, who used to stay home for exactly these reasons, an extra risk will be generated by their participation.

All the factors enumerated here will affect the state of affairs after (parts of) the
driving task will have been subjected to automation, and will contribute to the net effect on safety from this operation. When considering the separate stages in the progression of automation, as we will do in this paper, it will be of central concern which of the above effects will occur and to what degree. A fact of relevance in the present context is that automation of even the major parts of the road traffic system will not for a long time be complete and that it will not happen overnight. This means that not only will we have to deal with the aforementioned transition of individual drivers to some next stage of automation and its consequent processes of behavioral adaptation, but also with the fact that there will be transitions within the system (from automated to non-automated segments). Moreover, there will exist a mix in the driving population with respect to levels of automation of individual vehicles. This is particularly difficult to treat, in terms of expected behavioral effects, since it involves interactions between drivers rather than individual behavior. Nevertheless, serious attention should be given to them when it comes to estimating net effects of automation.

STAGE I: NAVIGATION AND LONGITUDINAL CONTROL

Navigation
In the order of 5% of mileage produced on current roadworks is estimated to be excess mileage (Jeffery, 1981). It is both due to non-optimal route planning and to drivers getting lost even after optimal preparation. Electronic navigation systems promise to eliminate excess mileage, as well as (at least) a proportional amount of road accidents.

There are reasons to expect that these promises will not, or not fully, materialize. Road users having navigation support may reasonably be expected to change their behavior on two counts. First, rather than stay home and enjoy their extra 5% time off users may plan a trip to an extra destination. Second, navigation support will invite users to venture into territory that they did not dare go into previously for fear of getting lost. If this is really complex territory it may then not at all be improbable to get lost despite the support provided by the navigation system.

Longitudinal control
Systems for collision avoidance, intelligent cruise control, cooperative driving, etc., are presently in advanced stages of development. There appears to be no discernible ambition here towards actually taking away ultimate decision power from the driver. For example, a European collision avoidance concept developed within the DRIVE-Project has the accelerator function as an active control when the vehicle gets too close to the preceding vehicle, while allowing the driver to overrule the pedal by an action of his own (Godthelp, 1986; Janssen & Nilsson, 1990). This being the case drivers who are armed with longitudinal supports have ample opportunity to adapt their general driving style in essentially counterproductive ways, while still being helped out of critical situations by the system. For example, in studies on the possible design of collision avoidance systems it was often observed
that following at very short headways to leading vehicles was indeed drastically reduced, but that drivers also showed a distinct tendency towards overall higher driving speeds (Janssen & Nilsson, 1990). The issue thus appears to be how one should design collision avoidance systems - and also other systems that support longitudinal control - that suffer minimally from these compensatory effects while, of course, fulfilling their primary aim.

Transition effects
That there may exist a mix of vehicles in this stage with respect to whether they possess navigational support and/or some form of longitudinal support is not too worrying. Both these partial supports, when engaged, do not directly make the traffic environment more critical for others. What is worrying, however, is that the less careful driving style that these provisions may encourage will put others at higher risk. Thus, those who have not got the supports not only do not have the benefits of these but may actually suffer from the behavioral adaptations of those who have them.
A transition that every user of partial support systems must make is from being a novice to becoming an old hand. It is at present not known how this learning process takes place. It is therefore too early to speculate about whether, and how, people should be taught the use of advanced technology as part of their education as a driver.

STAGE 2: INTEGRATED SYSTEMS AS CO-DRIVERS
The demand for integrated systems is already heard at this moment - for example, there is considerable effort within DRIVE devoted to it -, and it will become stronger the more it will be realized that it is worthwhile to treat automated support within the vehicle as a concept of its own rather than something that will emerge naturally from a collection of isolated components. An extra impetus will be added to this demand by the growing tendency to use vehicles as 'extended offices', introducing information streams that do not pertain to the driving task proper. There is then a need to think about ways to handle this potential informational overload in a coherent manner.
The core of an integrated support system is generally conceived to be an intelligence that supervises and filters the stream of information to the driver, and that prioritizes support in accordance with the prevailing configuration on the road and with the driver's momentary workload (Michon, 1992). As with the separate components of Stage 1 the intention is not, in existing projects we know of, to automatize the driver away but to suggest actions to him or to make an overrulable start with these by means of active controls.
Given that drivers will have this intelligent co-driver in their vehicle, how will they respond to the type of support that is offered?
The behavioral adaptation effects that already occurred in Stage 1 as a response to the modules for navigation and longitudinal control will just continue into Stage 2.
What is new, however, is the highly increased power of the intelligent co-driver to act as a watchdog over the driver's sloppiness in order to correct him in appropriate ways whenever necessary. It needs no great imagination to predict that this will be detrimental to drivers' overall level of alertness, and that because of this solutions will be required from the intelligent co-driver to problems that did not even exist before.

STAGE 3: EXTENSION TOWARDS LATERAL CONTROL

The reason why we have put the introduction of lateral control support only in Stage 3 of automation, even after otherwise integrated in-vehicle support systems have appeared, is that we feel that substantial changes in the road infrastructure itself will now be needed to accommodate any further automation. No longer will stand-alone and/or inter-vehicle provisions suffice to get the system going. Thus, although it could theoretically be done by sending course information from an in-vehicle sensor straight to the steering wheel it will most likely be by external course and position monitoring devices that lateral control will be exerted (e.g., Shladover et al., 1991).

The potential gain of automatic lateral control is, first, in capacity. If lanes could be half their current width, then throughput would double from this effect alone. The other gain would be in safety, by assisting in keeping individual vehicles on the road that threaten to go astray.

As in the previous stages of automation the issue will most likely not be whether to remove the driver from the loop completely, but rather in what - overrulable - way the driver should be supported. And, of course, lateral control would have to be incorporated in the already existing integral support system and its potential contributions at any moment scrutinized and prioritized along with those of other modules. With lateral control added the functions that lend themselves to be subjected to a certain degree of automation will be exhausted. It will be in this stage that drivers realize that automatons are keeping an eye on them in all aspects of the driving task. Next to continuing behavioral adaptation and loss in overall alertness this will cause the element of voluntary versus involuntary risk to become more prominent than it had been thus far. Thus, the perception that external agents are now taking care of a considerable part of their activities, and that this puts constraints on how they are allowed to handle situations themselves, will lead drivers to no longer accept the risk levels that they previously accepted voluntarily. This will then create an extra demand for safety that the Stage 3 - automated traffic system will have to fulfill. The most likely response to this will be a call for more automation, and this time the only remaining option is to grant full power to the machine.

STAGE 4: DEDICATED LANES

As an intermediate step to the ultimate stage of automation we may expect that separate lanes will be built - probably by reshaping existing 'fast' (lefthand) lanes -
to which only vehicles have access in which decision power has largely be allocated to the machine. The driver’s navigation task will be reduced to informing the system of a desired destination, and longitudinal and lateral interactions with surrounding vehicles will be regulated by straightaway interventions originating from a non-overrulable intelligence.

Assuming that technology will be capable of finding and implementing the appropriate intervention in each and every conceivable configuration - which by itself seems not totally guaranteed - there will be much less opportunity now for drivers to change their behavior in counterproductive ways. Testing the system to its limits may become a sport for some time, and there should be anticipation upon this phenomenon, but by and large acceptance of full automation should by this time be so general that technology may be applied to constrain what a driver can do to any desired minimum.

Does this mean that unsafety will finally be eliminated from the system?

It is hard to believe that this is actually going to be the case. As the required technology gets more complex it will also get more vulnerable to errors of design and maintenance.

When a technical malfunctioning occurs because of either of these we will then experience monumental pile-ups, both because situations have become intrinsically more critical and because drivers have lost the ability to deal with them. The consequent shift from frequent accidents with one or two victims to relatively rare, but much more serious, ones will then become a case for public concern.

Another effect that will become of real significance in this stage is that of transitions within the road network from the fully automated lanes to less, or non-, automated areas. Drivers who have to make this transition will experience the following: (1) A sudden demand for alertness at the transition point, after a ride on the dedicated lane that hardly demanded any attention at all. (2) After-effects of the supposedly extreme speed of travelling on the dedicated lane, with a resultant choice of driving speed on the lower-order part of the network that will be higher than intended.

STAGE 5: FULL AUTOMATION

In what is to be seen as the final stage of automation of the road traffic system all major connections will consist of dedicated lanes only. From the point of view of behavioral effects the introduction of this final stage is relatively uninteresting, since most effects will already have occurred in the previous stage. Nevertheless, they will continue to be of significance.

WHAT, THEN, ABOUT AUTOMATION?

It would be wrong to conclude from the previous pages that our view of the automation of road traffic is essentially negative. What we have hoped to make clear is that road users will not remain passive under
automation. They will most likely respond with behavior that makes a safety gain less than expected or lets it emerge as something else, a gain in mobility in particular. It is only by acknowledging this that one can get in a state of mind required to consider further interesting questions, like whether it is possible to design support systems that suffer less than others from the behavioral adaptation effects they evoke (it is), and whether it is still worthwhile to continue research into the possibilities of affecting traffic safety by other than purely technological means (it is).

What we have also tried to indicate is that automation, apart from the effects of induced behavioral adaptation, sometimes creates new problems per se to which explicit attention had better be given beforehand.

Together this would seem to come down to a realistic, rather than a negative, view of what to expect from the automation of road traffic. We are convinced that realism is more appropriate than the unwarranted euphoria that so often seems associated with the marvels of new technology.

REFERENCES


TRANSMODAL ASPECTS
ROAD SAFETY, TRANSPORT RESEARCH AND THE EUROPEAN COMMUNITY

A state-of-the-art overview

Paper presented at the 1st World Conference on "Safety of Transportation"
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M.J. Koornstra
Leidschendam, 1992
SWOV Institute for Road Safety Research, The Netherlands
ROAD SAFETY, TRANSPORT RESEARCH AND THE EUROPEAN COMMUNITY
A state-of-the-art overview

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ABSTRACT

The traffic safety situation in Europe is reviewed and the research and policy needs are discussed, partly on the basis of the so-called Gerondeau-report to the EC Commissioner of Transport by the High-level Expert Group for an European Policy for Road Safety.

The safety situation of (passenger) transport in different modes (road, rail, air and water) are compared and differences in their safety levels and approaches in research are discussed.

The momentary activities of the European Community in relation to road safety in transport research (DRIVE from DG-XIII and EURET from DG-VII) are discussed and differences with policy and research activities in the frameworks of the CEMT and the OECD are evaluated.

The aims and organization of FERSI, the in 1991 constituted Forum of European Road Safety Institutes, is presented and the recent involvement of FERSI in EC-affairs is discussed.

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1. RESEARCH AND ROAD SAFETY IN EUROPE

1.1. Road safety development

Since the Treaty of Rome the number of deaths in road traffic of the now twelve countries of the EEC has reached two million; the number of injured is over 40 million. The economic loss due to road accidents is very substantial and endangers the welfare in the community. Nowadays the macro-economic costs for the lack of road safety are about 70 billion Ecus per year in the countries of the EEC. The fact that this figure is larger than the Gross Domestic Product of, for example, Greece, Ireland or Portugal, demonstrates the extent of the losses involved.

The comparison of the fatality rate per kilometrage for road traffic between the countries of the EEC on the one hand and United States of America and Japan on the other hand shows that road traffic is half less dangerous in the USA and about one-fourth less dangerous in Japan than in the countries of the EEC as a total.

<table>
<thead>
<tr>
<th>Area</th>
<th>Motorkilometers 100 million</th>
<th>Fatalities within 30 days</th>
<th>Fatality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>34992</td>
<td>46405</td>
<td>1.3</td>
</tr>
<tr>
<td>Japan</td>
<td>6251</td>
<td>14595</td>
<td>2.3</td>
</tr>
<tr>
<td>EEC</td>
<td>19524</td>
<td>52689</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Table 1. Fatality rates 1990 in USA, Japan and EEC.

There are also large differences in risk on the roads inside the European Community. Per million vehicles the Netherlands and Great Britain have a rate of road deaths which is less or about 250, while the rates in Spain, Greece or Portugal are 3 to 4 times higher. The fatality rate per motorized kilometrage differs even more with a factor up to 7 for these countries (UK and NL about 1.4; Portugal 10.5; per hundred million vehicle kilometers).

In view of these figures and the differences in motorization between countries it has been argued (Koornstra, 1991) that the development of road
safety probably is driven by the increasing motorization. In the first evolution phase the degree of motorization and the level road fatalities are both low. The mid phase is characterized by a fast increase in motorization. At the end of this phase the absolute motorization is still at a moderate level, but the road safety worsened to a very high level of road fatalities due to the relative lack of safety provisions in the traffic system. Apparently the care for road safety is lagged in time with respect to the growth of motorized mobility. The last phase is the phase of saturating motorization and generally congestion is observed on roads in populated areas during peak hours. In this phase road safety is increased markedly and the number of road fatalities reduces very much.

Nowadays the south of Europe typically is in the mid phase, while the USA, Japan and North-West Europe has entered the last phase. Central and East Europe probably are just passing over from the first to the mid phase and the increasing motorization is indeed followed by the tendency of a sharp increase in road fatalities. By reducing the time lag between the developments of road safety provisions and the growth of motorization authorities can, if not to abolish, at least reduce the number and seriousness of road accidents. This asks for a proactive, instead of a reactive policy for road safety with respect to traffic growth.
The High-level Expert Group in their report to the High Commissioner of Transport in the European Community (Gerondeau, 1991, p. 15) states that the authorities have a fundamental part to play, through the action which they do (or do not) take. They are responsible for the road network and its equipment, for the standards applying in building and controlling vehicles, for organizing assistance and lastly, to a very large degree, for the opinions and the behaviour of road users, whom they can influence through education and training, information, traffic regulation, enforcement and penalties. The Gerondeau-report acknowledges that individual mistakes or bad conduct can be demonstrated in 90% or more of road accidents, but warns not to draw the wrong conclusion from that point. It states that: "the behaviour of every road user is in fact largely dependent on circumstances of his journey outside his control (road network characteristics, other users' behaviour, the regulations, the degree of enforcement, etc.)." A convincing illustration can be found in the fatality rate on motorways which is many times lower than on other main rural roads; it is hardly acceptable to assume that responsibilities of drivers on these roads are suddenly changed. The frequency of road user failures and the consequences vary considerably with the characteristics of the elements of the road traffic system he uses.

The Gerondeau-report concludes: "Whilst the part played in accidents by individual faulty actions of large numbers of users is often used as an excuse for inaction, there is a need for the awareness that, in spite of the appearances, the responsibility for taking action against traffic accidents is primarily collective and that it falls firstly on the various public authorities which might take such action. ...Progress is only possible through this approach, as is shown by the experience of those Community countries which have achieved the best results. ... That includes a commitment from the Community."

1.2. European Road Safety Policy

The Gerondeau-report formulates three general objectives for a European strategy for road safety. Firstly, the setting of quantified multi-year target, such as 30% less road fatalities by the year 2000. Secondly the harmonization of the safety levels in the Member States, encouraging the countries with low safety to catch up the advanced countries. Thirdly, the
promotion of a behaviour model for road users mindful of others. These three objectives can be reached, according to the Gerondeau-report, by adopting measures which have shown to be effective in reducing the number and seriousness of road accidents, but which are not applied in all Member States. It does not concentrate on modern electronics and telematics, despite the potential value which such measures may have. Nearly all the concrete proposals in the Gerondeau-report are already at least applied in one of the Member States with positive results on road safety which are judged to be also effective in the other Member Countries. The only innovations were some combinations of measures which were judged to yield a more optimal effect. The Gerondeau-report lists 64 proposals for such concrete measures. Not all proposed measures concern the European level, but on the level of the European Community action toward the national and regional levels can be taken by dissemination of knowledge and the pooling of experience in Member States. The EC should actively facilitate the adoption of proposed measures and if necessary, urge the adoption of some measures by Member States.

For this role of the European Community, the Gerondeau-report presents 14 proposals of a more process and organization oriented nature. The general idea beyond the scope of the 14 organizational measures of the Expert Group is the belief that there should be a coherent policy across the continent of Europe, and that the Community must involve itself in new ways of road-accident prevention expressed by four chief aims:
- to improve knowledge by research support;
- to produce technical reference material gradually;
- to establish a European 'Highway Code';
- to support road safety policy.

In the Treaty of Rome it was unclear what the authority of the European Commission is with respect to road safety, but in the treaty of Maastricht it becomes a duty of the European Community to improve European road safety and to establish a harmonized and optimized transeuropean network of motor freeways. The authority of the European Parliament on transport issues is increased especially on matters concerning road safety and this transeuropean network. In Brussels the Ministers of Transport have agreed to put the topic of road safety on their agenda and so they have done also for the agendas of their meetings in the CEMT.
It can envisaged that the Gerondeau-report will become, and partly is already, a source for action on the level of the European Community. The Gerondeau-report does not recommend the exclusive use of mandatory actions, but the coverage of road safety topics by the organization of advise to the national, regional and local levels of authority. That advise is thought to cover the following aspects:
- analysis of experience and action implemented in individual Member States in order to reveal the lessons of common benefit;
- initiation of new and participation in existing research programmes;
- publication of periodical surveys, information material and technical studies aimed at the public or specialists;
- compilation and monitoring developments in road safety, making use of a network of bodies in the Member States;
- production of recommendation or preparation of decisions at the request of Member States, the Commission, the Council or European Parliament;
- support to non-governmental bodies working on road safety.

1.3. Improved European road safety

The Gerondeau-report mentions the area's which are most beneficial for the improvement of the European road safety. I can not discuss all the 64 concrete measures that are proposed in the Gerondeau-report. However, the main principles beyond the proposals has been that human behaviour is not infallible and also that no one really wants to become involved in an accident by ones own behaviour. Nonetheless, the frequency of the seldom failures of millions of road users results in the enormous amounts of losses in road safety. The opportunity for failures is largely dependent on the human made traffic infrastructure. Therefore, increased road safety must be sought in an infrastructure which elicits less opportunity for failure as well as in an improvement of the road user interactions.

The Gerondeau-report proposes a dozen actions for infrastructural measures. The ideas beyond the infrastructure proposals are based on a hierarchical categorization of roads in the network with homogeneous characteristics along each type of routes. Each category should have a unique and uniform layout and the same should hold for the connection links within and between types of roads. Despite the gradual upgrading of the road system nowadays the road network still constitutes a more or less unpre-
dictable concatenation of a nearly infinite variety of road sections by an also nearly infinite variety of cross-connections. The result is a road system which is too complex for the road user to allow reliable predictions for the next oncoming situation. As shown by the illustrative Table 2 for Dutch roads, which together with the British and Swedish networks belong to Europe's most safe road networks, all road types other than motor roads and calming areas have considerable high injury rates.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Max. km/h</th>
<th>Mixing fast/slow</th>
<th>Level crossings oncoming traffic</th>
<th>Injury rate per million veh. km.</th>
</tr>
</thead>
<tbody>
<tr>
<td>calming area</td>
<td>&lt; 30</td>
<td>yes</td>
<td>yes</td>
<td>0.20</td>
</tr>
<tr>
<td>resid. street</td>
<td>50</td>
<td>yes</td>
<td>yes</td>
<td>0.75</td>
</tr>
<tr>
<td>urban arterials</td>
<td>50</td>
<td>yes/no</td>
<td>yes</td>
<td>1.33</td>
</tr>
<tr>
<td>rural roads</td>
<td>80</td>
<td>yes/no</td>
<td>yes</td>
<td>0.64</td>
</tr>
<tr>
<td>rural motor road</td>
<td>80</td>
<td>no</td>
<td>yes</td>
<td>0.30</td>
</tr>
<tr>
<td>rural motor road</td>
<td>100</td>
<td>no</td>
<td>no</td>
<td>0.11</td>
</tr>
<tr>
<td>motorways</td>
<td>100/120</td>
<td>no</td>
<td>no</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 2. Injury rate for road categories in the Netherlands 1986.

The lack of safety varies with the combination of the level of speeds, degree of separation (oncoming traffic) and the amount of variation in speeds due to discontinuities (level crossings) and mixture of slow and fast categories of road users on the road type. The urban arterial roads, where actual speeds are generally much higher than the speed limit, are the most dangerous ones. The redesigning of the road categories between motorways and residential calming areas to a limited number of categories of self-explaining roads with well predictable uniform layouts of routes and crossing types is most urgent. This is a major long term task which should be undertaken in a coordinated way on a European level, since diversity in the Community increases the unpredictability for the foreseen increase of cross-national travel of road users in Europe.

The ingredients of such a redesigned road network ask for more research on safer layouts, but some elements are know already. Separation of slow and fast traffic and traffic with large mass differences is one of the

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safe design principles. This means only pedestrians on sidewalks and cyclist on separated cycle paths, while crossings for pedestrians and cyclists on rural main roads and arterial urban roads preferably should not be designed as crossings on the same level. It also may mean special truck routes for inter-regional heavy good transport and limitation for trucks in urban areas, where delivery by smaller vans from just-in-time transit centers outside towns can be foreseen. Separation of tracks for oncoming traffic on rural main roads and urban arterial routes is also needed, combined with increased safety on reconstructed crossings and accesses to these roads. British research and research in France and the Netherlands has shown that the British round-about with priority for round-about traffic is a much safer level crossing than sign-regulated or unregulated crossings. Reductions to even 10% of the accidents has been observed after reconstruction of crossings to round-abouts in the Netherlands. The relative low share of fatal car-car accidents in the UK, compared to other Western European Countries may perhaps be explained by the frequency of the British round-abouts in their road network. On the other hand the British authorities could learn from other countries how their relative high share of fatal pedestrian accidents can be reduced.

The Expert Group in the Gerondeau-report, however, stresses that opportunities for failures are not only due to lack of infrastructural safety, but are as well elicited by the interactive behaviour of road users. Most concrete proposals concern the improvement of road user behaviour with respect to the others directly. The idea beyond them lies in the fundamental principal that human behaviour is conditional to circumstances and individual backgrounds as well as to the expected utility of the outcome of that behaviour. The individual background is shaped by public information, education and training, but mainly by the experience in traffic itself. That experience in traffic is not only conditioned by stimuli from the physical traffic structure, but also by traffic regulations and their enforcement and penalties. The behavioural proposals are directed to these domains which condition the road user behaviour. This can not be achieved by separate measures, but by packages of integrated measures with reinforcing components. Apart from the European harmonization in the proposals, the integrated scope of the proposals for (a) graded licensing based on accompanied learner driving, (b) speed regulations and (c) specific and general enforcement practices can be seen as the most important behavioural proposals for an effective road safety strategy.
If the proposals on the training and licensing of drivers by accompanied learning would lead to an application throughout the Community, then the risks of novice drivers could reduced considerably. The French experience with accompanied driver learning shows that skills and knowledge alone are not sufficient for safe driving by youngsters. If the French results apply in general such a risk reduction of young drivers could mean a 10% less serious accidents in total for the Member states. This means a gain of 7 billion Ecs for the Community; a cost-effective and important live saving measure indeed. If the validity for other countries holds, which has to be researched, it only depends on the political willingness of its adoption.

The level of mean speed and the variation in speeds are important factors in traffic safety. The deviation between speeds on the road (also between categories of simultaneous road users) determines to a large extent the opportunity for accidents. If the opportunity for accidents is reduced by a reduction of the deviation between speeds, than the number of accidents approximately can change proportional to the reduction in speed variance. That means a quadratic relation with the deviation from mean speed, as is empirically confirmed by Solomon (1964) and Cirillo (1968). The level of speed determines quadratically the seriousness of the outcomes of given accidents. Since deviation between speeds often reduces proportional with the reduction of absolute mean speed, it follows that mean speed reduction

![Figure 2. Annual number killed per 10^8 km on US Interstate highways.](image-url)
even can have a fourth power effect on safety. This for example means that a reduction of 10% in mean speed (factor 0.90) can change the number of road fatalities by 34% (factor 0.90^4 = 0.656). These considerations are confirmed by a Swedish study (Nilsson, 1982) and are also in line with results from speed limit changes on motorways in the USA and France in 1974 as is shown by an illustration for the USA data after the speed limit reduction after 1973 (Figure 2).

The Danish speed reduction from the urban speed limit change of 60 km/h to 50 km/h and the Dutch results on the so called "woonerf" by traffic calming measures in living areas which reduce speeds from 50 km/h limit to speeds below 30 km/h affirmed this relation between speeds and accidents. The network related proposals on speed limits and their enforcement and automatic control, therefore, are of utmost importance for the whole of the Community. This applies also to the German motorways, whereby together with a lowering the speed limits on rural roads it also can reduce the increasing share of traffic fatalities from rural roads in Germany.

The importance of the intensified and modified enforcement practices of specific and general police control can be illustrated by the results of random breath testing in New South Wales in Australia (Arthursen, 1985) Figure 3).

Figure 3. Annual fatal crashes and number of random breath test in New South Wales (after Arthursen, 1985).
These results show that a high density of random breath testing of about one out of three license holders per year leads to a lasting reduction in fatalities of about 25%. Such a high density is still cost effective and has a return rate of 2 for 1 cost unit as Dutch research has shown.

There is a long way to go before the next generation of road users is educated to behave safely and before a consistent road categorization can be established. The first steps, according to the proposals in the Gerdanau-report, are the conceptual creation of the hierarchical structure of the categorized road network and the clarification of regulations and behavioural principles on a European level. It is proposed to begin with the introduction of harmonized licensing system, harmonized speed and alcohol limits and their improved control as well as a periodically systematic and compulsory inspection of the safety of roads and the preparation and dissemination of reference material on all the principles and rules for the safest-possible traffic system.
2. SAFETY IN TRANSPORT MODES

2.1. Risk comparison

The safety situation is quite diverse for different transport modes. The safety of the road transport system seems in many respects less well developed. The risk in different transport modes only can be compared if we relate the frequency of accidents or fatalities to identical transport production or exposition measures. In the table below such is tried to estimate by kilometrage for road, rail, air and water transport and by person kilometers and by person travel time for the passenger modes.

<table>
<thead>
<tr>
<th>Fatal risk</th>
<th>Veh. km.</th>
<th>Pers. km.</th>
<th>Pers. hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road¹</td>
<td>2.7x10⁻⁸</td>
<td>3.5x10⁻⁸</td>
<td>1.0x10⁻⁶</td>
</tr>
<tr>
<td>Rail²</td>
<td>1.1x10⁻⁹</td>
<td>1.6x10⁻¹⁰</td>
<td>0.1x10⁻⁷</td>
</tr>
<tr>
<td>Sea³</td>
<td>0.6x10⁻⁸</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Air⁴</td>
<td>0.7x10⁻⁹</td>
<td>0.4x10⁻¹⁰</td>
<td>0.2x10⁻⁶</td>
</tr>
</tbody>
</table>

¹ EG; Gerondeau (1991) (1.3 pers.p.veh.; mean 35 km/h)
² North-West Europe; Schopf (1989); Zuber (1990)
³ Japan seacorridors; Hashimoto & Okushima (1990)(fatal/accid.=0.1)
⁴ USA; NTSB publications

Table 3. Risk per mode by several transport production measures.

For all transport production measures the risk of road transport exceeds the risks of other transport modes. Risks in collective transport modes, which can not be controlled by the behaviour of the user and are characterized by disastrous accident types, are clearly judged to be more important than individual risks in road transport. The annual total number of fatalities in road transport, however, are much larger than in any other mode of transport. The collective transport modes are constrained by strong safety regulations, as is the employer in the work situation. There, the safety rules which are imposed by the governments are much stronger than those which the same authorities impose on themselves by supplying the road infrastructure. Of course collective transport has a self interest by
the safety of its transport, because it has to attract the user to its mode of transport. However, one may ask why the governmental authorities do not judge the safety standards for the road infrastructure as equally important. Why is it that one type of death represents less value than the other? It seems not rational that road safety do not match the safety of other transport modes.

2.2. Safety optimization strategy

The way safety is optimized in the different transport is characterized by more or less the same strategy. The strategies are all based on the decomposition in frequencies of exposure to danger conditions and the severity degree of consequences of the danger conditions. On the basis of that decomposition it is tried to optimize the transport system by management for exposure to danger conditions and control of outcome severity. Dependent on acceptable safety levels for the decomposed categories a protection level is required for parts of the transport system. This is represented by the profile of Figure 4, taken from Zuber (1990).

In this profile the levels of outcome severity ranges from I (fatal /catastrophical) to VI (negligible), while the occurrence probability is structured from level A (relative high probability) level F (virtually zero probability). The more the identified type of hazard is located in the left upper part the more effort for its prevention is taken. Measures may reduce its severity level or its level of probability or both (for example in Figure 4 from I,B to III,C) in order to lower the danger to an acceptable one. Some measures only reduces the level of outcome severity.
(for example safety belt wearing in road transport) others only the frequency of occurrence (for example crossings on separate levels). Sometimes measures for severe outcomes do generate not intended new possibilities for less serious outcomes (for example traffic lights reduce accidents with severe side impacts, but create more rear-end accidents with less damage). The systematic analysis of severity and probability level and subsequent actions to lower the frequency of unacceptable outcomes is comparable for risk analysis and management in all transport systems. An excellent example of that strategy for rail can be found in the rapid rail system of Zurich opened in 1990 (Zuber, 1990; Röttinger, 1989). For the safety of ships in seacorridors the Japanese study of Hashimoto & Okushima (1990) is also a recent example. The study of Bush et al. (1980) describes the comparable strategy and analysis for air transport. Although the underlying strategy and principles are the same for all transport modes, the actual data analysis for the assessment of risks are different for road transport compared to the other modes. The data analysis in road safety is based on the statistical analysis of data of many actually occurred accidents, while for other transport modes the risk analysis is based on a priori estimates of possible frequencies and severity of outcomes. The strategy in road transport as a consequence is of a curative nature and in the other modes foremost preventive. This means a world of difference in thinking on safety.

2.3. Risk assessment: the big difference

The optimization of safety in rail, air and water transport can not gain very much by statistical analysis, due to the small number of accidents in these modes. Kanaf1 (1986) states that the risk difference between the actual 5 fatal plane accidents in the USA in 1979 and a conjectured number of 26 such accidents does not say anything about its acceptability. The first number means 1.7x10^{-9} fatal accidents per airplane mile and a fatality rate of 0.125x10^{-9} per passenger mile. The second hypothetical number with over five times more accidents in 1.0x10^{-8} fatal accidents per airplane mile and 0.65x10^{-9} death per passenger mile. Such risk figures hardly, so argues Kanafani (1986, p. 405-406): "by themselves would convey a significant different level of safety.... Realistically, while the public and system planners may be satisfied with the actual figures for 1979, as indeed they seem to be, it is very unlikely that anyone would tolerate a fatal airline crash every two weeks".

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Air, rail and water transport are considered to be safe if only accidents occur which are caused by combinations of factors which were not known to happen up to the time of their occurrence. The strategy for optimization of safety in these sectors is directed to the elimination of accidents possibilities which can be foreseen and avoided. Theoretical chance distributions of deviations from the ideal course of affairs are the basis for the mentioned analyses in Röttinger (1989) for rail, of Hashimoto & Okushima (1990) for seatransport and of Busch et al. (1980) for airlines. Such distributions of deviations always concern the possible presence of relative large differences in speed of transport carriers in the critical proximity of each other. Dependent on the probability and severity levels of such deviating situations, the transport system is adapted in such a way that on the basis of existing knowledge the system becomes “fail safe” in certainty approaching probability limits. If still a severe accident happens the system is subsequently changed on the basis of an in depth study of the chain of chance factors which have caused such accidents. In this way these transport systems become intrinsic safe designed or are modified to an inherently safe system. Automatic and electronic devices constitute the feedback mechanisms in these systems which interfere in order to eliminate possible consequences of remaining human failures.

This is in marked contrast to the safety strategy in road transport. Road transport is not designed to be fail safe, but evolved out of the mechanization of the coach and pedestrian transport system. Moreover, the changes in the system have not been based on the a priori elimination of things that can go wrong. A very demonstrative example of the post factum approach are the popular planes for investments of so called ‘black spots’, in stead of compulsory rules for an a priori optimal safe design of roads. In the road transport system there also does not seem to exist a safety inspection that is comparable to the ones in other transport modes.

Transition of safety knowledge between different transport modes is traditionally only based on knowledge from common background disciplines, such as ‘human factors research’ (Baise & Miller, 1978; Hale & Glendon, 1987) and ‘constructive crashworthiness’ or biomechanics in crashes (see Garret & Kidd, 1969). In view of the risk comparison of different modes it is clear that the other modes can not learn very much from road transport.
The reverse, however, seems very appropriate. A reconstruction of the road transport system to a designed system in which the non-negligible probabilities of failures are eliminated a priori, is the main lesson to be learned for road traffic. This also can be seen as the main issue in the infrastructural proposals in the Gerondeau-report, discussed in paragraph 1.3, which were aimed to establish such a safety strategy for a inherently safe road infrastructure in Europe.
3. EUROPEAN COMMUNITY ACTIVITIES

3.1. The need for actions

In view of the sad record of European road safety, compared with other industrialized continents as well as compared with other modes of transport, there clearly is a need for an active road safety policy. The Gerondeau-report has expressed the opinion that road accidents are too often seen as the inevitable price for the utility of travel and transport. And hence the possibility of an active road accident prevention policy is ignored. Such an active policy, however, can be possible on the basis of research and recommendations. The Gerondeau-report requests the European Community, that is the European Parliament, the Council and the Commission, to provide assistance in the work undertaken by the Member States against road accidents, because the Community is in the right position to do so. It has done so in matters of environmental protection and the advancement of science and technology in Europe. The Community should surely take a comparable action in a matter to which its citizens are highly sensitive, since it concerns the preservation of life itself and the safety of millions of its citizens. It seems not a too ambitious task to bring the level of road safety in the whole of the Community below the level of the USA, which is already nearly the level of safety in some of the more advanced countries in the Community. The achievement of such a modest target still would leave the road safety in the EC on a level that is over a 100 times more dangerous than other passenger transport modes, but it would save more than 20,000 lives and over half a million injured on a yearly basis. In such an achievement the national States (and their regional and local authorities) still have to play a major role, but on the Community level the research for the road safety knowledge as well as the promotion of and the assistance to the implementation of a common transport and road safety policy should be undertaken without further delay. At present there is no well staffed entity on the Community level that matches these tasks. The establishment of an organization, comparable to the European organizations for environment or technology, is needed barely in view of the economic and human problem of the lack of road safety in Europe. Up to now the transport related activities of the EC are mainly based on provisions and regulations for fair trade, but with the Treaty of Maastricht there is now a genuine task for the EC to deal with matters of European road transport and road safety.
3.2. European R&D-programmes

In the research and development programmes of the EC the research is mainly directed to technology in order not to be dominated by technological research and industrial developments in Japan and the USA. The technological research for transport got a push by the so called DRIVE-programme in which advanced electronics and telematics are researched for their application in road transport. The DRIVE-programme, because of its technological nature, is managed by the EC Directorate-General of Technology and not by the Directorate-General of Transport. The results of the first DRIVE-programme are now under way (DRIVE, 1991a) and the real life applications of that research with respect to the effects on road safety will be tested on the basis of recommendations of a special task force group (DRIVE, 1991b) in the so called HOPES-project of the DRIVE II-programme. In a recent OECD-report 22 field test on telematics in transport are identified and reviewed (OECD, 1992). It reveals that only 8 studies have given some concrete results or valuable progress in the evaluation of applications and that none of the studies has reported until now on the actual effects of road safety. The DRIVE-programmes, as the PROMETHEUS-programme of the collaboration between European motorcar industries, have been promoted as programmes which will bring a major unprecedented safety contribution to road transport, but it must be feared that the results for road safety up to now are rather disappointing or have to wait a very long period. For the moment the valuable contributions of DRIVE are mainly in transport efficiency, although potentials for road safety are undeniable also present. Probably the degrees of freedom in the road transport first have to be reduced, before more than informative advice systems can assist the driver on the road or can safely take over some of the driver's tasks.

To the third research and development programme of the EC, of which the DRIVE I and II-programmes are part, the less technological oriented EURET-programme for transport research has been added in a later stage. The EURET-programme had a limited budget compared with the high tech programme parts, but is directed to actual problems in the European road transport (EURET, 1990), such as transport regulations, economics and logistics. The EURET-programme is managed by the Directorate-General of Transport and contains some aspects of road safety related to freight transport. In this first EURET research programme, however, the lack of safety in European
road transport compared to other continents and other transport modes was not a central issue. This probably will change in the follow up of the EURET II-programme which is now in preparation.

The fourth framework for research and technological development, which is now in discussion between the Commission and the European Parliament, has a total proposed budget of 14.700 MECU for 1994-1998 and explicitly deals with transport and its safety improvement. It states: "The objective is to contribute to the development and management of safer, more efficient and cleaner transport means." The EC Directorate-General of Transport has taken the initiative to formulate under this framework a EURET II-programme. The first preliminary draft proposal for EURET II (EURET, 1992a) contains explicitly the topic of Road and Vehicle Safety apart from other more technological and road maintenance and construction topics. An annex in that draft proposal concerned short project description (the numbered topics below) and research suggestions (topics marked by an * below) on:

- **Road User Behaviour**
  1. Europinion (periodic comparative inquiry on road safety attitudes)
  2. Improvement of novice training and reduction of novice accidents
  3. Influence of legislation, enforcement practices and penalty levels
  4. Effects of speed and speed control.

- **Vehicle Safety**
  (* ) Assessment of passive safety
  (* ) Compatibility between different sized vehicles
  (* ) Improvement of frontal impact test
  (* ) Biomechanics of human tolerance in crashes
  (*) Improved restraint systems
  5. Lightning configuration.

- **Unprotected Road Users**
  (*) Efficiency of regulations and policies for vulnerable road users
  (*) Safety of two wheelers

- **Accidentology**
  (*) European observatory and 'road safety barometer'
  (*) Improved data collection and analysis on the European level
  7. European accident causation databank
  8. Harmonization of definitions of accidents.
Recently a preparatory workshop for the discussion of the draft EURET II proposal has been held in Brussels. Various working groups discussed the possible contents of the EURET II-programme and so did a working group on road and vehicle safety. That working group (EURET, 1992b) felt that the formulation of the fourth framework for R&D by the Commission of the EC still was not clear enough about the importance of road safety and proposed amendments to the Transport Committee of the European Parliament. The working group also noted that up to now the research proposals which were formulated in the draft document are not so much directed to the safety aspects of the infrastructure of the road network. The group referred to the Gerondeau-report and stressed that cooperative research is needed for the missing area of road network safety. A revision of the first draft proposal for EURET II on the basis of these discussions is to be expected. Its budget and its priority in the fourth R&D framework of the EC still is matter on which decisions are to be taken next year.

3.3. European cooperative research

The uniqueness of cooperative transport research for Europe is well demonstrated by the programmes, such as DRIVE and EURET. Its cooperation is quite different from the European collaboration in the preparatory work of State officials for the Committee of the European Ministers of Transport (CEMT). Although the work there is more than preparation of national administrations for collaborative actions of the 16 European States represented in the CEMT, it is restricted to exchange national experiences with transport related implementations of regulations in the different States and to dissemination of knowledge and national transport planes by round tables and conferences organized by the CEMT.

The activities of the OECD in the Road Transport Research (RTR) programme represent also a very valuable branch of international collaboration in the field of transport research. Its scope is broader than the EC or CEMT in that it covers the collaboration of research institutions from all over
the world. Besides the very useful collaboration in the documentation of the transport literature and in the databases for international comparative traffic and safety data, the work of the OECD/RTR mainly consists of up-to-date state of the art reports on transport research topics and transport policies. The research work of the OECD concerns the examination of the validity and the integration of existing research results from all over the world. How valuable this is does not to be questioned, but the work in the OECD/RTR does not, with some few exceptions, concern the actual doing of new research. In fact the OECD can not provide the funding for such cooperatively executed research and in the few example of actual cooperative research within the setting of the OECD/RTR, the funding has been based on ad hoc voluntary contributions of the participating nations.

It, therefore, must be concluded that the European need for cooperative transport research can only be fulfilled by programmes which are generated and funded by the EC. The cooperative nature of the research projects from the EC guarantees that the best experts of European research units join their forces in real innovative research with new empirical results and new potential applications. As a by product of such a European cooperation the results are easily acknowledged as valid in each of the nations and also will find their way in the national transport policies. As such this type of cooperative research has in itself, without mandatory regulations, a harmonization effect on transport in Europe.
4. FORUM OF EUROPEAN ROAD SAFETY RESEARCH INSTITUTES

In view of the needs in the European Community for an improvement of the relative bad road safety situation and for cooperation in research for an effective road safety in Europe the national road safety research institutes took in 1991 the initiative to establish a more or less formal organization for their collaboration and founded the Forum of European Road Safety Research Institutes (FERSI). Now the members of FERSI are national road safety research institutes of 12 countries in the EC or EFTA coming from:

- Austria, Kuratorium für Verkehrssicherheit (KfV);
- Belgium, Institut Belge de Sécurité Routière (IBSR);
- Denmark, Rådet for Trafiksikkerhedsforskning (RfT);
- Finland, Valtion Teknillinen Tutkimuskeskus (VTT);
- France, Institut National de Recherche sur les Transports et leur Sécurité (INRETS);
- Germany, Bundesanstalt für Strassenwesen (BASt);
- Netherlands, Institute for Road Safety Research (SWOV);
- Norway, Institute of Transport Economics (TØI);
- Portugal, Laboratorio Nacional de Engenharia Civil (LNEC);
- Sweden, Statens Väg- och Trafikinstitut (VTI);
- Switzerland, Schweizerische Beratungsstelle für Unfallverhütung (BEU);
- United Kingdom, Transport Research Laboratory (TRL).

The objectives of FERSI are in line with the recommendations of the Gerondeau-report and are achieved by:

- regular exchange between member institutes of information, experience, trends and new initiatives in research;
- the identification of research needs and opportunities for collaboration;
- undertaking joint research projects and sharing top-expertise and special (large and expensive) research facilities;
- furthering the development of European requirements and standards in the field of road safety;
- dissemination of the results of research by all possible means to policy makers, administrators, professionals and researchers in road safety and to the general public;
- encourage of exchange of researchers and of the set up and maintenance of appropriate data-bases.
In the spirit of the recommendations of the Gerondeau-report a conference 'Road Safety in Europe' in Berlin was organized in cooperation with FERSI in September this year. It is aimed by FERSI that this conference will grow out to the proposed major Road Safety Conference of the European Community. Under the umbrella of FERSI the initiative has been taken to propose some joint research projects for the oncoming second programme of European Research on Transport (EURET II) of the EEC. Some proposals (the numbered ones discussed in paragraph 3) are worked out now by members of FERSI, while other ones are only suggested as area's of interest.

The organization of FERSI will be the basis for formation of consortia of top-experts from the member institutes in order to perform the needed research on the highest quality level and with the most general validity of application in European countries. The fact that the outcomes of the cooperative research will lead to recommendations which are shared by the leading national institutes, is of great importance for the impact on national and European policies for road safety. The organization of FERSI is a first step which has to be followed by an organization that assists the EC Directorate-General of Transport in a European policy on road safety. It is envisaged now that the EURET II-programme indeed contains the necessary dedication for road safety research. Its funding probably will be approved in 1993 and its tendering will be opened presumably at the end of 1994. So at last the European Community is heading forward now in establishing the necessary funding and organization for safety research.

Road safety is, however, not only a matter of organization and political dedication. In a democratic Europe the basis for common action and their resource allocation is based on public support. The Community, therefore, should promote the need for a common road safety policy by an active social marketing and defeat the unjustified belief that road accidents are an inevitable phenomenon of motorized transport. Road transport is a man-made technology and this man-made technology can be made much safer. The know-how is partly there and can be further obtained by creative research, the organization for that improved safety and the measures for its realization can be proposed in concrete terms. The FERSRI is ready to provide the research based scientific input to policies and practices for an improved road safety of intergovernmental bodies and central and local governments in Europe, the response to the appeal has to come from these responsible bodies in the Community and from the EC itself.
REFERENCES

TRAFFIC AS WORK PLACE

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The Trade Union of Transport Workers FNV, affiliated to the FNV, has
a membership of 70,000. It represents railway-workers, dockers, workers
in the civil aviation, in the inland navigation and in the road
transport. In the Netherlands about 271,000 persons are working in the
Transport industry; 127,000 of them in road transport. In Europe about
7 million employees are working in the Transport-section, that is 6.5 %
of the total.

The safety and welfare of workers are principally protected by the Act
on Working Conditions. This act usually refers to factories. But the
working environment of workers employed in the transport sector for a
substantial part is formed by roads, rail and water. In the transport
sector many other laws are in use, such as the Rail Traffic Law and the
Road Traffic Law. The Act on Working Conditions has not been used in
Holland because of the existence of these laws. Since January 1992 this
Act is effective in the whole transport section.

Meanwhile developments are going on in the EEG. There is a European
concerning the realisation of measures for the advancement and improve­
ment of the safety and health of the employees (89/391/EEG; PB L183/1dd
29.06.1989). This directive must be effective/operative January 1993
through the national legislation of the member states. Along with the
Framework Directive guidelines are drawn up that protect parts of the
work of the employees.

One of these guidelines provides the employees with the means to enforce
health and safety in the workplace. However this does not apply to
workers in the transport sector. On a European level transportation is
seen as a special sector and therefore a Directive on the minimum
requirements on the working place in the transport sector is drawn up
(DOC 4141/91/ ref dd juli 1991). The target of this directive is to
provide minimum guidelines for the health and safety of all employees in
the Transport sector (rail, shipping and road haulage inclusive service
work). The question is at which time this directive becomes operative.

The first draft was presented to the Advisory Committee on Health, Safety
and Hygiene on the Workplace. This committee represents employers and
employees. The committee wasn’t very positive about this first draft.
First of all attention was drawn to the struggle of competence between DGV, DG III and DG VII. The committee also doubted the necessity of this European Rule in relation to already existing national regulation. The employers constantly "use" the principle of subsidiarity, by which they try to declare a European Regulation, although important for employees, environment and other social interests, not necessary.

"Transport has such a specific mondial character, that a special European regulation isn't desirable."

Because of the competitiveness of the Transport sector regulation is unwished.

Characteristic for the European Transport policy is the lack of generally accepted social regulations. The European Transport policy knows three keywords: privatization, liberalization and competitiveness. The possible interference of the national states has to stop in all sectors of Transport. Support of the state in any form is no longer allowed. The entry as employer to the transport market has to be possible for every European resident under the same equal conditions, so that fair competition is guaranteed.

Already for a long time labour is used as a closing entry for competition in the transport sector. This is because lorries, planes, diesel, taxes etcetera all have fixed prices. Competition through low prices is only possible by paying less to the workers in the transport sector. An employer can also compete through quality: in transport for example by being the best organizer of the logistic process in contracting cheap transporters (the process of sub-contracting). Both employers - the cheap transporter and the organizer, who contracts the transporter - have a common interest in inexpensive work. We can distinguish these tendencies in all sectors of transport: roadtransport, railway, aviation and shipping.

National regulation, which formulates extra conditions for the access to the international transport market, is forbidden. In transport this is a great disadvantage, because transport activities are conducted on the road, in the air, on the rail and on the water. They can - different form the product industry - be organized and coordinated from every arbitrary place of business. The national regulations concerning social and safety aspects of the national countries differ very much, and the entrepreneur who has established his company in the "cheapest" country, has a competition-advantage.

National regulation to protect work in the transport sector isn't satisfactory any more and European Regulation at this case fails to occur.

Moreover Europe omits to ratify important ILO-conventions. Convention 153, which protects the working times in the transport sector, is ratified by only seven countries. Europe is missing on this list.
The lobby of transport employers is strong. The European Community fails in the field of a good regulation of working- and restperiods. Through the privatization, deregulation and liberalization the wages are reduced, working times are extended and the informal sector has grown. The transport sector has not gone along with the common trend of reducing working hours. Research has showed the connection between nightwork, long working times and accidents. Regulation is urgently desired. So this is a second example of European regulation at the field of protection of labour, where employees in the Transport sector are excluded.

A further directive will be made concerning several aspects of the organization of working hours. The draft-guideline contains conditions with regard to the minimal daily break, weekly-restperiod, the annual holiday, the normal working time, shift work, overtime work and the medical care for nightwork. The road-transport, the civil-aviation, the workers in the inland navigation, they all will be excluded of the protection in this Directive.

In road-transport a Regulation for driving- and restperiods exists: the 3820/85 Regulation. But this Regulation does not have any effect. Mr. van Miert suggests this also. You can read this in the White Book, when it will be published. An efficient control system is lacking. Besides this, the Regulation uses the wrong definitions. The General Regulation deals with working times, but the Regulation 3820/85 defines driving- and resthours. Only driving is estimated as work and all the other activities are counted in the restperiod!

The unions of Transport Workers have been struggling for a long time to get better definitions into the Regulation. We proposed to amend the Regulation 3820 in order to fix maximum limits of dutytime. And dutytime includes all the activities a driver has to do: checking and attending to a vehicle and its load; loading and unloading a vehicle; attending to requirements of passengers, waiting for frontier formalities to be carried out, waiting for a ferry; doing administrative work concerning a vehicle or its load, cleaning and so on.

We submitted this proposal for amending the Regulation in favour of the limitation of the dutytime to the employers in road transport and to the European Transport Council. It did not succeed. The employers have thus far resisted all arguments.

In november 1991 Mrs. May, at that time President of the Transport Council, indicated that 6 countries were prepared to discuss such an amendment. Six countries refused: Germany, Great Brittain, Italy, Spain, Portugal and Greece.

A similar pattern can also be seen in Civil Aviation and in Inland Navigation.

Although little known outside the aviation industry, the Joint Aviation Authorities (JAA) have been taking on an increasingly important role in
the regulation of aviation safety in Europe. This body is composed of the national aviation authorities of all EEC and EFTA member states. All EEC states have agreed that they will accept the JAA Regulations as the sole code. The ITF has been closely involved in JAA work. But the flight time limitation is not yet regulated. An acceptable proposal is still not produced after 2 years of work and 19 different drafts.

Also in the Railway sector the regulations and care for health and safety are lacking. The question of privatization of railway-activities is of considerable concern to respective trade unions. A particular danger is seen by the separation of infrastructure responsibility and operating responsibility into distinct entities. This is made possible is opened by the EC Council of Ministers’ decision of June 1991. The free access to railway-infrastructure may not cause a lack of safety. The Transport Trade Union FNV a few months ago addressed the Dutch Parliament and the Minister of Transport about the safety on railways in the future and ahead:

* Which official language will be spoken by users of the Dutch railway infrastructure?
* Who will make the safety-inspection of the trains, which do not belong to the Dutch Railways?
* Which duty-times will be handled, what qualifications will be required by railway-workers and will the medical examination be continued?

These questions have not been answered in the regulations made by the EC, when it made the EC-Directive on free access to railway-infrastructure. Expanding transport policy in Europe causes new developments in the construction of vehicles and other means of transport, new concepts and new transport systems. The degree, in which the transport workers – physically and psychologically – can copy with their work situation is of enormous importance for the transport safety. Not only for workers, but also for others involved in traffic.

I am inclined to place some remarks here. In the development of the TGV will the engine drivers and the workers on infrastructure be taking into consideration?

In The Netherlands two mainports will be developed: Schiphol and the port of Rotterdam. New systems will be developed to accelerate the inland transport to and from these centres.

On a special road semitrailers are driving, appropriate for the transportation of 4 TEU-containers of the ECT-grounds to the distributive centres. Are these constructions tested on how manageable they are? Because of the congestion the road transport has to be moved to the night. But the earlier mentioned ILO research has shown that nightwork increases safety risks. The Minister of Transport just started an inquiry into the effects of night-work. But nightwork in roadtransport is already increasing.
Will the implementation of the board-computer serve the driver or will the board-computer rush him? Will it lead to safe dutytime-systems or to longer driving hours and less restperiods? Will the board-computer make it possible, that the driver can make his own decisions or will the driver be steered by the satellite?

Is there any place for the worker in the Transport-sector? Conspicuous in the advice on the Guideline Protection Transport Activities is the remark of the employer members of the Committee that less attention must be given to regulations on constructions of cabines. At this time these regulations are different in each state of the EC. In practice the cabine-room is the rest of total allowed measures of the vehicle minus the wanted room. And with the differences between the national standards the competition can be hold. This means unfair competition on labour conditions and a bad working-environment for the driver.

Conclusion: the transport workers have a minimum-protection on health and safety. National regulation differs and there is a lack of European regulation.

The protection is restricted to the direct working-place: within the vehicle, within the train or within the ship. The regulation does not deal with the situation on the roads and the rivers. Traffic is "the workplace", but this place is not protected by the law on Working Conditions or by European Regulation.

At this point the transport worker and the traffic participant meet one another.

For both of them many measures are requested: the overspeed-deciver; the limitations in working hours of the transport worker. But more essential is that the development of a European Transport Policy has to take into account the human factor.

Not only the policy makers but also the designers and the constructers of transport products have to take into account this human factor. An old principle 'rules': "Human is the best moderation of all things."

The International Transport Workers’ Federation (ITF) formulated in their action program for a European Transport policy: The Common Transport policy must give the highest priority to Transport safety, in the interest both of transport users and of workers.

Stringent new safety regulations should be adopted at community levels for each mode of transport, and in transport coordination attention should be paid to the safety implications of expanding individual rather than collective forms of transport.

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ANTICIPATORY RESEARCH FOR THE DESIGN OF A SUSTAINABLE AND SAFE ROAD TRAFFIC SYSTEM

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Abstract

The new policy in the Netherlands is trying to build a traffic system, based on clear design concepts and rules about how to use it. Such a system should be sustainable and safe. The design characteristics of the roads should agree with the function they have; it should be clear which vehicles are allowed and which traffic rules apply. Incompatible road-users should either be separated or else be integrated on the basis of survival of the weakest. Road users should be prevented in a natural way from exhibiting unsafe behaviour or suffering from such behaviour of other road-users.

The basic problem is how to design such a system, in the context of physical planning, demand and supply considerations concerning mobility, design criteria for the infrastructure in relation to the functions of the roads, the permission of the types of vehicles and the regulations for the behaviour of road-users.

In order to support the design of this future traffic system by research, the Ministry of Transport took the initiative to ask the major research institutes working on safety or traffic problems directly related to safety, to cooperate in the development of a programme for anticipatory research, starting in 1993.

Proposals for research are integrated into a programme and presented to the Ministry of Transport. The framework of this research programme is described, together with the procedure for integration of the results.
1. Introduction

For a long time the policy regarding the development of the traffic and transport system and particularly its safety aspects was reactive, more than prospective. This was caused by the explosive development in motorization after the Second World War. No experience had been built up regarding such massive transportation systems yet. Society first had to learn how to deal with this type of problems. Particularly the developmental speed of the transport system left no room for careful planning, but only for dealing with the problems of today. Learning how to cope with such problems for the society as a whole (including politicians, planners, road and car constructors as well as road-users) takes time. Oppe (1991) shows that it takes about ten years to get efficient answers to problems at this scale. After the seventies the speed of growth of motorization slowed down and the safety problem diminished; the number of fatalities decreased instead of continuing to increase as before.

After a successful period of improving the safety of the traffic system, there was a feeling in several countries during the eighties, that a more prospective safety policy instead of a reactive one was necessary. Quantitative targets were set and plans developed to reach such targets. At the "Evaluation '85" conference held in Paris, the need for more systematic and consistent safety programmes were stressed by a large number of contributors (Biecheler c.s., 1985). Safety policy should become an inherent part of traffic policy.

The new policy in the Netherlands was first to define a national safety plan for several years: "Het Meerjaren Plan Verkeersveiligheid (MPV)". This plan worked for several years and on the basis of it a more integrated safety policy was developed. In the beginning, this plan ran parallel to another plan "Het Structuurschema Verkeer en Vervoer (SVV)", a coherent plan for the further development of the traffic system in the Netherlands. Recently, both plans are integrated, in order to develop a "Duurzaam Veilig" (sustainable and safe) traffic system. The aim is to come to a final configuration of a sustainable and safe traffic system in the Netherlands, based on clear design concepts and rules about how to use it.

The design characteristics of the roads should agree with the function they have in traffic. It should be clear which vehicles are allowed and which traffic rules apply. Only a small number of road types with consistent characteristics should be accepted. Incompatible road-users should either be separated or else be integrated on the basis of survival of the weakest. Road-users should be prevented in a natural way from exhibiting unsafe behaviour or suffering from such behaviour of other road-users.

The basic problem is how to design such a system, in the context of physical planning, demand and supply considerations concerning mobility needs and how to formulate design criteria for the infrastructure in relation to the functions of roads, the permission of (types of) vehicles and regulations for the behaviour of road-users.

In order to support the design for this future traffic system by research, the Ministry of Transport took the initiative to ask the major research institutes, working on safety or on traffic problems directly related to safety, to cooperate in the
development of a Programme for Anticipatory Research, starting in 1993. After an inventory phase and discussions between research institutes and road administrations, final proposals for research have been integrated into a programme and presented to the Ministry of Transport.

2. A sustainable and safe traffic and transport system

In order to get a sound base for a future traffic and transport system, it is necessary to start from the beginning: from the basic principles underlying human communication and mobility. A reflection on the safety problems in the current traffic and transport system shows a number of fundamental controversies within the system:

- economic interests, such as fast and good transportation versus social interests, such as environmental quality and safety;
- aggregated traffic and transport interests versus the interests of individual road-users;
- transport of goods versus transport of persons;
- the need to use public areas for the transportation of persons and goods over long distances in short time versus the need for playing, walking or shopping, without any time stress;
- differences between vehicles in mass, speed and direction, or in vulnerability of road-users.

The problem is how to solve these intrinsic controversies and how to arrive at consequent and consistent solutions. This asks for a reanalysis of the underlying processes to find directions for a solution of the problems within the system as a whole, instead of looking at improvements for isolated parts of the system.

The four most important aspects to be distinguished within the traffic and transport system are:

- the traffic generation phase and the need for a traffic infrastructure, that copes with the potential needs for mobility;
- the traffic distribution phase; the management of traffic over the road network, given the actual trips planned by the users;
- the traffic realization phase, regarding the actual road-user behaviours and their interactions;
- the crash phase, concerning conflicting traffic behaviour that runs out of control, leading to damage, injury and their treatment.

A short description of the safety aspects within these phases will be given as well as the needs for research.

2.1. Safe mobility

The major question is how to control the need for mobility by influencing demand and supply. Research with regard to demand should focus on:

- the relation between physical planning and the safety of traffic and transport;
- origin and destination of trips, concerning travelling motives and their changes
(resulting from changes in industrial activities and population seize and composition, together with changes in travelling needs), including prognoses of future demands and how to change these demands to improve safety.

Research on supply should focus on:
- how to deal with congestion problems safely;
- changes in modal-split and their safety consequences including preferable changes from a safety point of view.

This research should start from the main purpose of the traffic and transport policy: to create possibilities for realizing trips that are wanted and to minimize trips not wanted.

Starting from this point, quality demands need to be settled for safety and environment. This means that safety prognoses should be added to mobility prognoses and safety consequences given for mobility scenarios. Save alternatives should be formulated in case of expected safety problems. Safety arguments do not play an important role in this trip generation phase yet.

2.2. Safe traffic distribution

In this second phase the major problem is to distribute traffic safely, given the actual travelling needs. There is a strong connection with 2.1: the design of the road network should be consistent with the main functions of the network and its elements. A small number of clear road categories should be selected with a consistent lay-out of the elements, given the specific function in the network. Given this lay-out, the function of the road and its elements should be unambiguous and tell the road-user clearly what behaviour is expected from him and what he may expect from others. Motorways and "Woonerfs" are good examples of clear categories, but the categories in between, in rural as well as urban areas, are much more hybrid and confusing. These other categories are more difficult to handle, because of the mix of functions they have at the moment. However, even roads with equal functions, have a large variety of solutions at the moment. At road sections with a "stream-function", the safe distribution of traffic should be stressed. Traffic modes or traffic streams that endanger each other must be separated in time or space. At the urban network the main focus should be on the necessary conditions for protecting pedestrians and bicyclists. Applications of electronics and telematics should be studied more in relation to these problems than to motorways as is the case now, because the safety potential is much larger for these areas.

2.3 Safe traffic behaviour.

The traffic system at the moment is far from fail-safe. The final responsibility for safety is not put into the hands of professionals as in many other transport systems, but of road-users themselves. One of the most important pillars for a sustainable and safe traffic system in the near future is background knowledge about traffic behaviour and the causes for errors that lead to accidents in the existing system. The three main aspects are:

The personal and social context of behaviour. It concerns knowledge about motives, values and norms. It should not only be clear to the individual road-
user what kind of behaviour is expected from him, it should also be acceptable for him and his social environment. Attitude change and group behaviour only change over relatively long time. Measures aimed at such changes (e.g. in speed-behaviour, drinking and driving, car use etc.) should be based more on (social) psychological principles than on laws and their enforcement.

- The relation between behaviour and the traffic environment. It concerns the relation between behaviour and the lay-out of the road, the vehicle used, weather conditions and the composition and characteristics of traffic streams. There is an intimate relation between this aspect of behaviour and the problems described in 2.2. A central issue here is conflicting behaviour of road-users. The most relevant types of such critical behaviour are looking behaviour, priority handling, manoeuvering and speed behaviour. New technologies are available to study critical traffic behaviour in the real traffic environment.

- The behavioural change caused by learning or loss of functions. It concerns the degree of difficulty of taking part in traffic, the complexity of the traffic situations and how natural the supposed behaviour is. It should be based on ergonomic principles and general rules for human interaction. There is a considerable increase in safety with experience. What road-users learn and how they learn this is almost unknown to us. For the elderly the same can be said with regard to the function-loss and its relation to safety. Longitudinal and cross-sectional research is necessary to increase our knowledge and to find ways for improving the system as well as the education and training of road-users.

2.4. Controlling the damage of accidents
Although the traffic system is far from being fail-safe, this does not need to imply that its consequences should be accepted. It is hard to think of a traffic system in which no accident occurs at all in the near future. However, it should be unacceptable already now, that these accidents end up with fatalities or serious injuries. Speed, mass and (lack of) energy absorption are the main factors in injury causation. A lot of research has been done to improve cars and their traffic environment. Less is done with regard to unprotected road-users. A sustainable and safe traffic system should be based on tolerance norms for vehicles at specific roads, depending on the function of the road, the traffic composition and the road-users allowed. These tolerance norms should be based on maximum acceptable violence that may result from possible errors in traffic for other road-users. This counts for speed control especially.

2.5. Scientific framework
Research on traffic safety is carried out by very many different disciplines. There is (bio-)mechanical research on the physical forces that play a part in accidents; there is research on the safety of the infrastructure; safety improvements on vehicles; ergonomic studies on road and vehicle design related to the abilities of road-users; there is psychological research on perception, cognition, decision making, problem solving, task-analysis etc.; there is mathematical/statistical accident analysis; medical research etc. These researchers do not speak each others language and don’t
understand each others methodologies. In order to work together at a framework for a sustainable and safe traffic system, their knowledge and ideas should be integrated. Apart from the projects that are directly related to the problems described above, a horizontal project is proposed, to bring the results together and integrate the knowledge of the different projects. Furthermore, attention is given to the development of methods and techniques necessary for future research. This is particularly the case with regard to the applicability of electronics and telematics for the improvement of road safety. As said before, at this moment too much attention is put to the application at motorways. However, these roads are already the safest and little can be gained here. The analysis should be focused on the search for modes of application of telematics for the major safety problems and to stimulate the development of applications for such areas.

3. Conclusions

A further analysis of the problem areas as described above resulted finally in the choice of twelve research proposals, which will only be mentioned:

1. Physical planning and safety
2. Mobility (developments) and safety
3. Safe road design
4. Safe traffic distribution
5. Situation dependent traffic behaviour and accidents
6. Telematics and traffic safety
7. The personal and social context of traffic behaviour
8. Behaviour and the (task) environment
9. Behaviour and learning
10. Collision research
11. Scientific framework (horizontal project)
12. General methodology and methods for evaluation

The organization of this research programme for anticipatory research will also be different from the traditional approach. The projects will not be executed by separate research institutes. Consortia of institutes will make joint proposals for research on each topic and researchers from various institutes will work together in the resulting projects. All institutes will be involved in the development of the scientific framework and the coordination and integration of research on the different topics. Inconsistencies between research findings and proposed solutions from different projects will be discussed.

Furthermore, it is stressed that such a programme, in order to be successful, should be supported by strategic plans at a political and administrative level. This presupposes a central government which:

- stimulates, by defining and up-dating goals and directions for a sustainable and safe traffic system;
- coordinates implementation, in order to get a consistent and coherent system;
- evaluates implementation, not just on final safety outcomes, but also on the quality of the plans.
A permanent body, consisting of researchers and administrators, should be installed for information exchange and to support political and administrative decisions.

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TOWARDS INTERNATIONAL COUNCILS
INDEPENDENT INVESTIGATION OF TRANSPORTATION ACCIDENTS

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Abstract

The primary reason for investigation of transportation accidents - or any accident - is to learn what happened, and why it happened so that changes can be made to prevent the recurrence of similar accidents. In order to avoid any appearance of conflict of interest, the council or agency conducting the investigation must be totally separate and independent from the agency, ministry or company that is responsible for operations, regulations or surveillance. This independence eliminates the partisan or proprietary influence -- whether they be real or imagined -- that are present when an agency investigates itself. An independent investigating council is totally free to look at all aspects of the accident, including institutional factors and to make recommendations without concern for past decisions. The true and only agenda of the independent investigator is to improve public safety. This independence also lends credibility to the investigation in the eyes of the public and the policy makers who must act to correct deficiencies revealed by the investigation. Without public support, the changes necessary to improve safety are often difficult or even impossible to bring about.

The most effective and efficient way to accomplish independent accident investigation is to have one council or agency responsible for investigations in all the modes of transportation. This allows for the sharing of safety information, accident investigation techniques and the more efficient use of technical experts. For example, specialists in certain fields such as human performance, meteorology, survival factors and the release of hazardous materials can work on investigations in more than one mode of transportation.

This presentation will discuss the advantages of the independent, multi-modal approach to the investigation of transportation accidents.
Legislative History

In 1966, the United States Congress created the Department of Transportation (DOT), which brought together all of the modal agencies that had responsibility for transportation. In the safety area, each administration had a somewhat different safety mandate, and, of course, unique operations as a result of modal differences and practices.

This same legislation created the NTSB, which had a primary function to investigate, or cause to be investigated, all aviation accidents and certain specified accidents in the other modes of transportation, to determine the probable causes of these accidents, and to issue recommendations to correct any safety problems discovered. Although it was autonomous in the exercise of its functions, the NTSB was housed within the DOT for administrative purposes. To guarantee its independence, the NTSB was directed to report to the Congress annually.

By creating the NTSB, the Congress intended that the Government would concentrate attention to safety in a body to which no other functions would be assigned. It also envisaged that this new body would develop a much higher degree of expertise, if only by freeing those involved in safety from the responsibility of discharging other functions that demand their time and attention. Congress concluded that formation of this independent body would also eliminate distracting, partisan or proprietary influences that are often present when accident cause must be determined by the same body that is responsible for operations, rulemaking, surveillance or regulation. Finally, Congress noted that, having established a department in which agencies responsible for safety functions were grouped, the gains would not be fully realized if one or more modes of transportation were left out.

Among its statutory duties, the NTSB is required to investigate (or cause to be investigated) and determine the probable cause or causes of accidents in all modes of transportation; to formulate safety improvement recommendations; to initiate and conduct special studies and special investigations on matters pertaining to safety in transportation; to assess and reassess techniques and methods of accident investigation; to assess the effectiveness with respect to the transportation safety consciousness and efficacy in preventing accidents of other Government agencies; and to review on appeal suspensions, revocations, or denials of operating certificates or licenses by the Federal Aviation Administration or the U.S. Coast Guard.

In passing the Independent Safety Board Act of 1974, Congress noted that proper conduct of the responsibilities assigned to
the NTSB calls for the making of conclusions and recommendations that may be critical of or adverse to the transportation modal agencies or their officials. It further stated:

"No Federal agency can properly perform such functions unless it is totally separate and independent from any other ... agency of the United States."

In addition to making it completely independent, the Independent Safety Board Act of 1974 gave the NTSB a somewhat broader investigative mandate, especially in the marine mode. The Act provided that the Board should investigate in addition to its original mandate, any accident "...which, in the judgment of the Board is catastrophic, involves problems of a recurring character, or would otherwise carry out the policy of this title."

NTSB Operation

In establishing the NTSB, the Congress recognized that there were considerable differences between the statutory responsibilities and the accident investigation practices and procedures of the modal agencies which formed the DOT, and the NTSB's enabling legislation was written to accommodate these differences rather than to resolve them. However, the NTSB has had considerable success in melding these diverse practices and procedures into a relatively standard mode of operation in investigating and reporting on accident causes and recommending improvements in all modes. Most notable of these successes might be the introduction to the surface modes of the multidisciplinary Go-Team approach to accident investigation. This approach was developed in the late 1950's as a means of augmenting our small investigative staff by compartmentalizing the investigation into as many as 12 specialized technical groups, each headed by a Board specialist and staffed by knowledgeable experts provided by the parties-to-the-investigation from government and industry who are invited to participate in the fact gathering phase of the investigation by the Investigator-in-charge. This concept has worked well, both in small investigations with but a few investigators, and in an investigation of a catastrophic air carrier accident in which 70 experts from government and industry participated; it permits the NTSB to manage these large groups without losing control of the investigation to the parties. However, only the NTSB and its staff analyze the facts, develop the conclusions, determine the probable cause and issue recommendations.

While the team investigation concept also provides for the DOT regulatory agencies to participate in the accident investigation to whatever extent they believe necessary to assess the safety effectiveness of their regulatory programs, the NTSB does not permit modal regulatory staff to
concurrently investigate for disciplinary purposes while they are participating in the Board's investigation.

Over the period of a week, these teams conduct the field phase of the investigation, collecting critical factual information. At the end of each day, they compare data at a progress meeting. This is followed by a press briefing by the Board's official spokesperson at an accident -- the Member on scene.

After the on-site phase is completed, the Board begins the painstaking analysis process of an accident investigation. It usually takes between 6-9 months before the full investigative process is completed. This includes scheduling a public hearing, drafting the report and holding a public board meeting in Washington to determine the probable cause of the accident and to issue any safety recommendations the Board believes necessary.

It is important to note that the Safety Board can issue safety recommendations at any time during an investigation -- an in fact, it often does.

Today, the NTSB is an independent agency with about 370 full-time staff which has jurisdiction over accidents in all modes of civil transportation, albeit with varying degrees of investigative authority with respect to each mode.

The NTSB has had its least success in integrating the marine mode into its accident investigation processes. In highway, the NTSB investigates accidents "... that it selects in cooperation with the States ..." While generally good, the degree of cooperation of the 50 States does vary somewhat from state-to-state. The NTSB's jurisdiction in the marine mode was quite limited in the DOT Act of 1967; this was increased in the Independent Safety Board Act of 1974. The 1974 Act left total jurisdiction over investigations of major marine casualties to both the USCG and NTSB.

Currently, under the terms of Memoranda of Understanding between the Board and the USCG, the Board has three options it may exercise in the investigation of most major marine casualties: it can conduct the investigation for cause independently; it can participate in the fact-finding investigation with the USCG, but determine the probable cause independently; or, it may delegate the entire fact-finding investigation to the USCG, and make its causal determination based on the USCG record.

The NTSB is one of the smallest agencies in the U.S. government. Yet, every civil aviation accident in the U.S. -- more than 2,000 last year alone -- is investigated by NTSB experts. The NTSB even participated in the investigations of two space vehicle accidents including the Challenger
disaster. In addition, NTSB investigated 250 selected rail, highway, marine, pipeline, and hazardous materials accidents.

A visit to the Board's laboratory points out the variety of work the NTSB does. During a recent week it was piled high with a helicopter jet engine, a wheel bearing from a railroad freight car, a u-joint from a large truck and the landing gear from a general aviation aircraft.

It must be stressed that the NTSB's effectiveness to a great extent comes not only from its independence, but from its mandate to investigate accidents in all areas of transportation.

Because the agency is involved with all transportation modes, its investigation of accidents is much more economical and efficient. A separate complete investigation staff is not required for each of the modes. A number of technical investigative specialties lend themselves equally well to the conduct of investigations in several or all of the modes of transportation and equally important, lessons that are learned in one mode of transportation can be applied to other modes.

The Safety Board is comprised of a five member board, nominated by the President. The Members are confirmed by the Senate for staggered five-year terms. One member is nominated and confirmed separately as Chairman for a two-year term.

The NTSB role is that of an independent safety watchdog. The Safety Board's responsibility is to the American people. The Board represents the public whenever and wherever transportation safety is an issue.

The NTSB, in effect, sets the safety agenda. In doing so, the Safety Board operates with a degree of independence that surprises most people.

Safety Board makes safety recommendations to anyone in a position to make changes that improve safety. This includes government agencies, associations, private businesses and labor unions. In its 25-year history, the NTSB has made almost 9,000 safety recommendations.

These recommendations aren't regulations. They're advice. When the Board's analysis of an accident are accurate and its recommendations sound, that expert advice is often taken. Currently the acceptance rate for the Board's recommendations is more than 80 percent.

When someone disagrees with the NTSB and no good counter argument is given -- or if promised action gets delayed -- the Board keeps on pushing. The Board asks for a reconsideration. It request progress reports, and continues
to publicize its concerns. The Board becomes a safety advocate.

Frankly, pushing for change sometimes requires making life uncomfortable for people who are the object of the Board’s recommendations. After all, no one likes to hear they are part of the problem. Often the Board’s persistence and candidness sometimes undermines its popularity in government and in the private sector, however they also save lives.

The Safety Board is unique. This is because it affects the kind of change in the system frequently associated with agencies that have regulatory authority. The NTSB is able to get the job done without all the trappings and encumbrances of the full regulatory process. Some would say NTSB regulates by the power of the raised eyebrow. There is no force of law behind the Board’s recommendations. We would like to keep it that way, despite efforts from time to time to make the Board’s recommendations mandatory. Perhaps the most important reason for this is because NTSB does not operate or regulate any transportation systems, it has no institutional interest to protect when it conducts an investigation. This allows the Board to be completely objective during the process of its investigations and in its findings and recommendations.

Benefits of Intermodal Operation

As the Safety Board gained in experience in intermodal operations, many benefits from this type of operation - in addition to those perceived by Congress when it established the Board - became apparent. These benefits can be considered to fall into three separate categories: economy of operation; transfer of safety lessons learned within and between transportation modes; and development of improved investigative techniques for use in one or more mode.

Economy of Operation

- A separate complete investigation staff is not required for each of the modes; a number of our technical investigative specialties lend themselves equally well to the conduct of investigations in several or all of the modes. We now list on our Go-Team roster a separate group of such specialists, who can be called upon for any investigation.
Application of the Go-Team concept of investigation, which was developed in the aviation mode, has resulted in significant economies of Federal resources in investigating accidents in all modes.

One Board office provides overall management of our safety recommendation development and follow-up systems for all modes.

The close working relationship between the Board’s small investigative staff has made it easier to share information across the modes than it would have been if the investigatory units were located in the separate modal administrations.

The timely exchange of safety information brought about by the Go-Team approach to accident investigation frequently results in faster corrective action by the regulatory agencies or by the industry involved.

Information regarding current significant safety issues in all modes is disseminated to safety professionals, to the news media, and to interested observers by the Board’s conduct of public hearings during its accident investigations and by symposia/forums held by the Board to air selected safety issues.

The Board’s advocacy role is resulting in more uniform state driving-while-intoxicated laws, blood alcohol testing procedures, and handling of those arrested for drunk driving.

The safety lessons learned in the highway mode relative to alcohol and other drug misuse are now being used to address the problem in the aviation, marine and railroad modes. In these modes, the use of alcohol and drugs by operators is being combatted by a variety of activities ranging from regulatory testing measures to promotional activities pointing out the hazards of mixing alcohol and drug use and vehicle operation.

Our human performance specialists now examine the factors which may have influenced the performance of persons in all modes of transportation whose actions have contributed to the occurrence of an accident or incident such as (a) the background of the person as it may have affected transient performance, including activity during a pre-accident period, rest, habits, and critical life or stress-producing events, (b) the physical ability of the person to perform, including general health, physiological and sensory factors, drug/alcohol ingestion, (c) the adequacy of the procedures, knowledge and training of the person for the
task, the person’s experience level, work habit patterns and the interrelationships with other persons including management, (d) the specific task requirements as they impinge upon human capability such as time for critical decisions, workload, and physical strength requirements, (e) the equipment design including the operator-equipment interaction dynamics (ergonomics), comfort, display information transfer, and controls, and general workspace layout, and (f) the environment as it may affect the person’s ability to sense and perform, including illumination, noise, vibration, motion, and external atmospheric/geographic conditions and characteristics.

- Our survival factors staff are applying crashworthiness improvement technology/equipment developed for one mode of transportation to the other modes. Examples of this include the development and installation of nonflammable seat and wall coverings and of emergency exits and emergency lighting in passenger-carrying vehicles, whether they are airplanes, buses, passenger vessels or railroad passenger cars.

- The Board was instrumental in getting the highway (NHTSA) and aviation (FAA) administrations to develop child safety seat requirements which met the needs of both modes; previously, these were being developed independently, and seats approved for use in one mode could not be used in the other.

- Board meteorologists have demonstrated that a meteorological phenomena called a microburst, which has caused a number of aircraft accidents, is also a hazard to marine small craft.

- Board accident investigation reports have stressed the need for the government to provide timely and accurate weather information to operators in modes other than aviation (e.g. to alert railroad operators of possible flooding conditions and to alert fishing vessels of forecast severe weather conditions.)

- The Board’s success in locating crashed aircraft by means of Emergency Locator Transmitters (an electronic signaling device activated by crash forces) has led it to promote the need for similar equipment - the Emergency Position Indicating Radio Beacon (EPIRB) to locate vessels which have sunk.

- The Board’s success in the use of flight data and cockpit voice recorders in aviation has led it to urge the use of data recording devices in other types of transportation vehicles to improve our accident investigations.
Board railroad investigators are striving to increase the use of radio equipment for the dispatch and control of trains, having seen the value of the radio in controlling air traffic.

Board marine investigators also are promoting the use of certain air traffic control methodology for use in marine vessel control in U.S. harbors and congested waterways.

Board marine investigators are promoting increased usage of radios in marine vessel-to-vessel meeting situations in addition to whistle signals which may be less informative in some situations.

Board highway and airport specialists are working together to solve vehicle skidding/hydroplaning problems on both highways and airport runways.

Much of the NTSB's activity regarding the transportation of hazardous materials (HM) in the United States has centered around the transfer of knowledge gained in one mode to the other transportation modes.

Much of our experience with the performance of intermodal packaging during accidents in one mode may be directly transferable to other modes.

Problems observed in the labeling, marking, and sometimes in the placarding of HM for transportation in one mode have enabled Board investigators to evaluate whether this information is adequate for use in other modes.

HM loading procedures in more than one mode are frequently similar, and lessons learned in one accident about such problems as static electricity discharges during loading of flammable materials apply to the loading of these materials in the other modes.

The performance of HM when released, or when subjected to intense heat in postcrash fires, is predictable from one mode to the other. For example, while the explosive potential of a BLEVE was first experienced with a railroad tank car, it was predictable that it could also happen to a highway tank truck.

The Board's experience in HM emergencies has helped it to bring uniformity to the notifications of HM emergencies by/to local and Federal authorities, and in the establishment of a system for local authorities to use in getting timely technical assistance from the chemical industry in dealing with problems.
Board experience with inadequacies observed in the response of local authorities to HM emergencies in all modes has helped us provide local authorities with general guidance regarding procedures and techniques for preparing for, and handling, such problems. For example, we have assisted in educating the nation’s firefighters that the best method of dealing with a HM fire is not always to immediately rush in and attempt to extinguish it.

Improved Investigative Techniques

Most notable in this category has been the Board’s success in introducing the Go-Team concept of accident investigation to all of the transportation modes in the United States.

The level of the technical expertise of our team investigations constantly increases as more representatives of parties-to-the-investigation gain experience in Board accident investigation technology.

As a focal point of accident investigation, the Board conducts training courses for government and industry investigators in all modes, which is an efficient means of transferring investigative technology, and a means of standardizing various techniques used by state and local police throughout the United States.

The NTSB has been instrumental in changing the law to permit the investigators in all modes to access the National Driver Register (NDR) in the conduct of accident investigations. Thus, if the causal area appears to involve the performance of the operator, aviation, railroad, or marine investigators can review the NDR to determine if it indicates that the operator may have a long-term problem such as alcoholism. The NTSB also asked the FAA to review the NDR before it issues airmen’s medical certificates. The FAA began such a matching program in 1991.

The Board has promoted techniques for analyzing alcohol involvement in highway accidents which are now being used to combat the operation of boats, airplanes, and railroad trains while under the influence. For example, in order to determine if there is cause for arrest, marine police are being trained to use such field tests as gaze nystagmus for detection of alcohol impairment of the operator.

The Board was the original promoter of aircraft flight data and cockpit voice recorders (CVR), which have significantly improved the quality and timeliness of accident investigations.
As its investigative experience with the cockpit voice recorder grew, Board specialists found that they could retrieve and make use of much data other than records of cockpit conversations; an example of this is the detection of engine malfunctions by analyzing engine frequencies recorded by the instrument.

The Board has also significantly improved its techniques for electronically enhancing the fidelity of CVR tapes in order to extract more useful data from them.

Board specialists have applied computer graphics technology to illustrate the final maneuvers of aircraft involved in accidents; this technology is now being adapted to investigations in the highway and railroad modes.

An investigative technique which has been long used by aviation investigators to determine if an electric light bulb was illuminated at the time of impact (e.g. a system failure warning light) is now applied by investigators in all modes.

Conclusion

It is very clear, based on 25 years of experience that the best way to improve transportation safety is through independent accident investigation, and the most effective and efficient way to accomplish this is to have one council or agency responsible for investigation in all the areas of transportation. This system also facilitates the sharing of safety information and accident investigation techniques with investigative agencies and councils in other countries.
FLYING IS NOT SAFE

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Abstract

Many distinguished scientists have provided papers for this congress. As an airline pilot I am about the only one active at the operational end of transportation, which you could also call the receiving end when we are discussing accidents. In other words: for many of you safety or subjects related to safety are interesting and challenging topics in scientific terms. For us, airline pilots, safety is literally a matter of life or death. And not only for our passengers. We promise them a safe flight and by sharing that flight with our passengers we provide the ultimate guarantee: our own life. That goes a few steps beyond putting your money where your mouth is.

We fully subscribe the aim of this congress which I take to be to advocate the creation of a European Transportation Safety Board. Aviation is pretty new. Once people like the Wright brothers overcame the initial technical problems of manned flight and flying became a mode of transportation it needed an organizational structure. A lot was then copied from shipping. We still use nautical miles and we still carry red lights on port and green lights on the starboard side of our aircraft. However, the air-ocean is even more unforgiving of mistakes and ignorance than the cruel sea. So we had to develop additional procedures and deeper insights into the causes behind accidents to survive. What we learned and what I will address in this paper might very well be useful for other modes of transportation too. While we started out with receiving information only, we are now ready to repay our debt and give some information back. At the same time, in the spirit of this congress, we are eager to receive any information that could help us further on the way to our common goal: safe transportation.
Aviation is not safe.

This title needs a bit of clarification. Because if it were true as is, I would not be standing here. One more line should be added, a line that reads: at least not automatically. Flying is easy however, but only for birds. A 1897 drawing shows the skeletons of a man and a bird drawn to the same height to indicate that these two look basically the same, implying that flight should be possible for men too. However, although they look the same, the bird bones were especially adapted for flight over an evolutionary period of about 120 million years. And so was the bird brain. We don’t have bird bones and we don’t have bird brains. So to be able to fly we need a lot of technical contraptions. That is the first problem making flying inherently dangerous.

The second is, that once mankind learned how to fly we were not content with a nice circuit around the local church on a lazy Sunday afternoon. We wanted to fly always, day and night, and never mind the weather: we wanted to fly in rain, snow and fog, in weather when the average bird would wisely decide to sit tight on his twig. And we wanted to fly on time, to keep a dependable schedule. This called for even more technical contraptions, posing even more potential problems in more adverse circumstances.

Third problem, once a bird starts flying and the situation deteriorates, he can call it a day and sit down on the nearest telephone wire or in the nearest tree to await improvements and get rested. Once man starts flying he is committed to continue, whatever happens weatherwise or technically. He can only stop when he finds a piece of concrete long enough to land his aircraft on.

Yet it is possible to provide a safe flight as we prove day in and day out. But safe flight is only possible under very specific conditions. Where the borders are that outline the area within which safe flight is possible we learned the hard way. We learned it literally with blood, sweat and tears. Those borders are marked with the wrecks of aircraft and the remains of passengers and crew.

Safety does not exist

You might wonder what the Dutch Airline Pilot Association or, for that matter, IFALPA, the International Federation of Airline Pilot Organizations has to do with safety. The answer is: a lot, and for a long time too. If we mark the beginning of aviation at 1903, the first flight of the Wright brothers, or Orville to be more specific, on December 17th, aviation is 89 years old. VNV, Dutch
ALPA, is the oldest pilot organization of the world and was founded in 1929. Aviation is a very global activity and to have an effective voice you have to be organized globally as well. That is why IFALPA came into existence, founded in 1948 with VNV being one of the founder members. So we, as VNV, are 63 years old and right from the very beginning safety was one of our major concerns. And with good reason. The first board of VNV counted five members. One of these failed a medical check, which ended his career. The other four all ended their career flying. Literally: every one of them died in an aircraft accident. So much for the safety level of that pioneer period.

We have come a long way since those days. The indicator we use to show how we are doing safety wise is "hull loss per million departures". A more common statistic used is "passenger seat miles per life lost". The latter one is indeed a good parameter for a potential passenger deciding on the best way of transportation for a given trip. However, most aircraft accidents happen in the take off or landing phase and do not depend very much on the size of the aircraft. So if you let bigger aircraft fly over longer distances, your safety record based on the latter indicator improves automatically without having done anything else. For knowing how you are really doing hull loss per million departures is more informative.

If we pick up the statistics in the late fifties we find them coming from 45 losses per million departures, decreasing rapidly to about 1.5 per million in the early seventies and remaining stable at that low rate till now. So despite great increases in the complexity of modern aircraft, much heavier traffic density and more adverse environments (we now land and take-off in dense fog where you would not even want to ride your bike) we see a dramatic and stable improvement in flight safety. This would be great, were it not for the fact that safety does not exist. What exists is a level of safety. When we say driving a car is safe we mean that we feel it is safe enough to drive a car to actually do it. Safety is relative, and unfortunately not even that.

Most people consider negotiating Niagara falls in a barrel pretty unsafe. The safety level has proven to be not quite zero, as some people actually survived such a ride. Chess on the other is considered by most people to be a quite safe activity. Driving a car ranks somewhere in between, but is also considered by most people to be safe enough to do. So far so good. But then we get to the funny part. Airline flying has been proven to be considerably safer than driving a car. And indeed a great many people find it safe enough to do. But there are also many who will either never ever enter an aircraft or do so when they really
can not avoid it but are then scared out of their wits for the whole duration of the flight. So safety is not only relative, it is also subjective: it is a perception. And as they say in modern management perception is reality.

A neat demonstration of this reality has been provided in the US in the year 1985. In that year 45,000 people died in automobile accidents. With a population of 240 million at that time the probability of dying in a car accident was 1 in 5,300. That year was also marked by many terrorist attacks against US targets abroad. 17 US citizens died in those attacks that received widespread newscoverage. 28 million US citizens made one or more foreign trips that year. So the probability of dying in a terrorist attack was only 1 in 1,600,000. These are the objective figures. Yet the next year I think not one US citizen decided to leave the car alone for a year, while millions of them cancelled their foreign trips. Here in Amsterdam the international hotels were half empty and the total economic loss in the Netherlands alone was in the order of 200 million guilders.

Going back to our stable rate of 1.5 losses per million departures that meant about 18 accidents with the 12 million departures a year we had at the end of the eighties. If we however combine that stable rate with the doubling of traffic that is still expected by the end of this century, we will then have 24 million departures with statistically 36 hull losses per year. Which translates into a smoking wreck on the tv screens almost once every week. Imagine what that will do for the perception of the safety level of aviation.

Human Factors and System Failure

So this problem needs to be addressed. If no solution were possible you could define it as a public relations problem and go to work on that. However, we feel real improvement is still possible. Although of course it will be very difficult, which is indicated by the fact that despite all efforts the loss rate has stabilized at 1.5 losses for quite some time now. When addressing a difficult problem it sometimes helps to look at its parts. Which is the case here. Although aircraft accidents are almost always the result of a complicated train of events, investigating authorities have the habit of attributing the accident to one major final cause. When you brake down the accidents of the last thirty years according to various major causes the result is very interesting. Although the actual number has diminished quite a bit, the division among the several causes has remained basically unchanged. About 75% of the accidents have been attributed to flight crew failure. What used to be called pilot error in the past and what we prefer to
call human factors. Not because we do not want to be blamed, but because we
do not want the investigation and learning process to halt once it is found that
the flight crew did not function as expected. We want the investigation to
continue and to investigate why the flight crew did not function properly.
Obviously not by choice, because the pilots are normally amongst those killed.
Before we go a bit further into this human factor area and even expand it into
system failure I would like to illustrate my point with a classic example of what
used to be called pilot error.
In the beginning an aircraft carried an altimeter with only one needle, indicating
hundreds of feet. When aircraft started to fly higher a shorter second needle was
added, indicating thousands of feet. Finally, when cabins became pressurized and
even higher flight altitudes became possible and economical, an even shorter
third needle was added indicating tens of thousand of feet. Thus was the three-
pointer altimeter created. Then a lot of fatal accidents started to happen
because of misreading of this altimeter. The cause: pilot error. These stupid
pilots should learn to read their altimeters correctly. Even when they are tired
after a long flight and have to land in adverse weather conditions, they should
not make mistakes. But mistakes and accidents continued to happen: you can not
order a human being not to make mistakes, as you can not order a human being
not to become ill. People are not omniscient and infallible. Even pilots aren’t.
Eventually it was decided to change the altitude presentation and after several
failures in this area we now have a very satisfactory altimeter that gives the
altitude as a digital readout and on top of that uses a needle to indicate the
hundreds of feet, thus providing rate of change and direction of change
information.
This is what pilot error is. Of course this is a very simple example and all the
simple items have by now been eliminated. However there are still many
complicated ones lurking within the system and it is the task of all of us active in
aviation to track these down and to eliminate them. As pilots of a specific flight
we are standing on top of a pyramid of activities leading to that specific flight.
The base of that pyramid is the design of the aircraft and some of the
subsequent layers are the manufacturing of the aircraft, its maintenance, the
tanking of fuel for the specific flight, the providing of meteorological
information, the providing of air traffic control services for that flight, and so on.
And at any level in that pyramid things can go wrong and things do go wrong. As
a matter of fact, standing on top of a pyramid of activities is a glorious image,
and I therefore wish it were true, but it is not. Reality is that we are not the top
of a pyramid but more the stop in a funnel. With the design of the aircraft as the
topmost level. And in every level, as stated before, things can and do go wrong. All these things drift down to ever lower levels. Sometimes they are detected in the process. A failure in the manufacturing stage might well be detected in the maintenance levels. But some failures drift all the way down till they reach the pilots. The pilots add to those latent failures their own failures and mistakes, because they are not infallible and omniscient, and they have to cope with the resulting explosive mixture. Normally we do cope, normally we are able to handle whatever we find on our plate. But occasionally a potential failure falls through and a major accident is then the result.

This of course is what we set out to prevent: we want a lower accident rate, even lower than the already low 1.5 we have. When we picture the pilot as a goalkeeper we have two ways to improve our record: we can improve the goalie and we can try to reduce the number of scoring opportunities. For both we have to analyze what went wrong. We have to analyze the full accident train and cannot stop at the verdict pilot error or even human factors. A problem, all be it a luxury problem, is that we have not enough accidents to make enough progress. We must therefore also learn from incidents. And we are at the moment studying ways to make available the information about our day to day operation that is stored in the computer memories of modern aircraft for maintenance reasons. Of course the use of these types of information depends on the willingness of individual pilots to come forward with reports of things that, although handled nicely afterwards, were things that were done wrong or went wrong in the first place. It stands to reason that the individual will only be willing to provide all necessary details if the objective of the procedure is clear and endorsed by everyone involved: the objective must be to learn. Not to apportion blame. Progress through learning, those are the keywords.

**The changing role of the captain**

As a matter of fact we have learned quite a few things already. The two most important ones are a different perception of the role of the captain and the realization that the complete system that should be studied goes far beyond the aircraft/crew combination; it also involves management and authorities. As far as the role of the captain is concerned we see quite a change over the years. In the beginning pilots were considered to be just plain hero’s. And they were. If we look at the fifties, we see the captain, like so many things in aviation at that time, modelled after what had been succesfull in the nautical world. The
Captain as Skipper next to God. It was probably the best model at that time in the prevailing circumstances. However, a captain is not infallible nor omniscient, so over the years a new model was developed. We nowadays view the captain as the manager of all the people and resources he (or she) has available both inside and outside his crew. But not as the type of manager common in hierarchic bureaucratic organizations, but as a different type. A type that can be defined by just two words: communication and information.

We learned that to be able to use all available resources to the fullest communication is essential. Not only must the captain communicate what he intends to do and why, he must also be open to receive any signals others may send. A first officer must always feel free to make any comment he sees fit, he must be convinced that he will never be ridiculed nor frowned upon whatever his remark.

We learned that we have to realize that the mental picture we have of any given situation is a perception and not necessarily an actual representation of the real world. So we must always be open and ready to adjust that perception.

We learned that the human mind can handle only a limited amount of information at the same time, that once the mind is focused on an important item other items and even new items tend to be ignored, even if these new items may rapidly lead to far greater problems than the one at hand. We call this the "deadly set" as we have seen at least two cases of aircraft crashing while the attention of the crew was focused on in the final analysis minor problems.

We have learned that decision making is for most people a traumatic experience and that once a decision has been made the natural tendency is to not take it into consideration again. New facts indicating that a decision was a bad one tend to be ignored, with sometimes disastrous results.

We have learned that most people like to belong to a group and that it is for many people difficult to go against the views of the group, and especially against the views of the leader of the group.

With all these subjects communication and information can be the items that save the day.

To summarize the comparison of the manager role of the captain with the traditional manager model: the aim is not to give directions and then check if these directions have been followed closely. The aim is to use all people and means available. The captain does not pretend to be omniscient and infallible. He does have trust, in his own capacities as well as in those of other people. Although he knows he will make errors, he is also aware of his own skills and he is confident he can handle almost any situation. He has to trust himself for two
reasons. First it enables him to trust other people. When I take a 747 for a flight to New York I am responsible for and I sign for its technical status. I have no way on earth to really check what I sign for. I trust the ground engineer and the organization behind him blindly. And I trust my own skills, I am convinced that if they made a mistake and if we lose an engine just after take-off, that I will be able to handle that. Second trust in his own skills makes the captain open for criticism. If he knows he does a good job he will accept a critical remark for what it is: addressing a factual situation. He will act upon that remark and he will not take it to be an attack on his person or his functioning and get distracted into addressing one of those issues while the aircraft continues its perhaps fatal flight.

Of course this implies that the aviation environment must be basically fault tolerant, so that one fault is not by definition fatal but that error recovery is always possible. And it also implies that we must be willing to learn from every event.

Furthermore we cannot manage safe flight through fixed rules and fixed rules alone. Things always go wrong in unexpected ways, so knowledge and tools are needed to handle every possible situation. That is also the reason why the human being cannot be designed out of the loop. As artificial intelligence experts have come to realize expert systems can only assist humans, not replace them. And the computer systems we have should be adapted to the human mind. Asking the human to adapt to the computer, which has been customary in aviation, is asking for trouble.

System failure

All this only addresses the functioning of the pilot in his crew on a specific flight. However, we should also regard the pilot in the total system, we should look at the complete funnel of activities trickling down to a specific flight. Major work in this area has been done by the Professors Reason, Hudson and Wagenaar. They developed a powerful model to address many safety issues in a broader perspective.

Traditionally there was an accident and there was the cause of the accident, in our case a mistake or, more generally speaking, an unsafe act by the crew. The traditional reaction has been to tell the pilots not to commit unsafe acts, which is pretty useless, to devise more rules and procedures and/or to install defence lines: warning systems. Like ground proximity warning systems, altitude alert
systems and, the most recent addition to our multitude of horns, lights and artificial voices, TCAS, a Traffic alert and Collision Avoidance System. When a simple error will lead to a major accident a defense line is certainly needed. Relying to heavily on defense lines however carries additional risk: breaking through a heavy defense line, which will happen sooner or later, will very likely lead to a very serious accident. A side effect can also be that the real problem is not addressed: why should one bother when there is a defense line to counter unwanted situations at no additional cost. This is one of the problems that might crop up with TCAS. TCAS is meant to prevent midair collisions, in other words to catch failures in the Air Traffic Control system. It might be very tempting for authorities to rely more and more on TCAS instead of correcting weaknesses in the ATC-system.

So, although defense lines and additional training and procedures certainly are useful they also have their limitations. In the end they lose their effect: it does not help much to impose ever more regulations and warning systems if you do not address the underlying causes.

The first level of underlying causes lies still within the crew: these are the psychological precursors and are common to mankind. You cannot change them, but you have to take them into account when designing procedures, instruments and warning systems. These are things like the fact that we are likely to be the victims of visual illusions. Or that we respond better when receiving information about changing situations through more of our senses at the same time. The reason why a fire in an engine not only lights a warning light but also sounds a horn. Also the reason why it is very useful when an automatic throttle system not only changes engine rpm but also moves the throttle handles in an appropriate way.

Other precursors are the fact that the human brain can handle only a limited amount of information at the same time and feeding it more information will lead to overload and to not noticing sometimes vital information, and the fact that our memory has its own limitations and peculiarities. A lot of this is well known and specific training to counter these problems is available. Generally speaking this training is aimed at teaching more effective cockpit communications.

With the next two levels we proceed beyond the crew: they fall within the scope of management. The first of these are what we call latent failures, mainly caused by the second one: management decisions.
Latent failures are for instance not having efficient standard operating procedures and not using standard calls to inform other crewmembers of changes in the aircraft configuration. Or having a confusing layout of checklists and/or manuals or unclear or even faulty information in manuals. Other categories are technical shortcomings or software bugs that are known but not corrected.

Management decisions finally are things like allowing very tight schedules, thus putting even more pressure on on time operations than normal. Or buying aircraft without a defense line proven to be useful like a ground proximity warning system only because the national authority allows operation without that system. Management can make a great many decisions that in itself might look harmless or even justified but that in effect reduce the safety margins a pilot has and a pilot needs when several things go wrong at the same time. Instead of error tolerant the total system then becomes vulnerable causing latent failures to lead through psychological precursors to the commitment of unsafe acts that may break through defense lines and cause a major accident. This scenario and this model can be applied to all modes of transportation and in all cases a major accident will be the likely end result.

The only way to prevent this is for management to become safety conscious and to be open to feedback that has to be provided by the users of the system. In these areas too a European Transport Safety Board could play an important role.
1 Introduction

Even as long ago as the seventeenth century - the Golden Age of the Dutch merchantman - shipping accidents were subject to inquiries. However, these were largely internal investigations conducted by shipowners - the most prominent being the Dutch East India Company.

In 1879, all Dutch shipping became subject to accident investigations for the first time, when a disciplinary board was set up to apportion blame between captain, mate or chief engineer.

The disciplinary board was succeeded in 1909 by the Maritime Court of the Netherlands, a board of inquiry which has a wider brief than its predecessor, with the power to investigate the causes of an accident as well.

What follows is an account of Dutch maritime legislation and the work of the Maritime Court of the Netherlands.

2 The Ships Act and its implementation

Chapter I of the Ships Act contains the preamble, and Chapter II contains specific measures for preventing shipping accidents. These measures cover safety specifications, inspections, and professional qualifications. Safety specifications are defined more rigorously by the 1965 Ships Decree, which contains detailed regulations dealing with certification, the condition of the hull, engines, other machinery and crews.
By virtue of powers delegated to him, the Chief Inspector of Shipping has imposed a wide range of binding safety regulations by issuing Notices to Shipping. If the Maritime Court makes a particular recommendation in its ruling, for instance, the inspector may make this binding in a Notice to Shipping.

The section of the Act dealing with inspections states that all Dutch ships are subject to government inspection at any time. Inspections are carried out by the Shipping Inspectorate. A ship which, in the opinion of the inspector, does not comply with the safety regulations may be impounded. The owner has the right of appeal to the President of the Maritime Court.

Chapter III of the Ships Act relates to the Maritime Court and the Commission of Inquiry in the Netherlands Antilles. The Commission was set up to deal with ships sailing under Antillean registration papers, and serves a similar purpose to the Maritime Court in the Netherlands, except that it does not have the power to impose disciplinary measures. If the Commission considers that such measures are called for, it refers the case to the Maritime Court.

I shall say no more about the Commission on this occasion.

Chapter IV of the Act covers shipping accidents. I shall come back to that in section 3 of this paper. Section 4.4 deals with disciplinary measures covered by Chapter V of the Act. Chapter VI of the Act lays down penalties that may be imposed by a criminal court for contraventions of the Act.

3 Accident investigations

The Ships Act defines as a shipping accident any incident in which significant damage is caused to a ship or its cargo, or in which one or more of those on board are injured. Other incidents which could provide a lesson in safety are treated in the same way as shipping accidents.
The accident investigation procedure applies to Dutch ships wherever they may be in the world. Foreign ships in Dutch coastal waters, inlets or sea ports also come within the jurisdiction of Dutch accident investigators. Investigations of this kind provide valuable lessons for Dutch authorities and organisations.

The Ships Act requires all shipping accidents to be reported to the Shipping Inspectorate, and defines the powers of inspectors to carry out preliminary investigations. A typical accident investigation will consist of a preliminary investigation carried out by the Shipping Inspectorate, followed if necessary by a Maritime Court inquiry. The Shipping Inspectorate must institute a preliminary investigation for every shipping accident.

The Shipping Inspectorate is part of the Directorate-General for Shipping & Maritime Affairs (DGSM), which in its turn forms part of the Ministry of Transport, Public Works & Water Management. The Minister is therefore accountable to Parliament for the work of the Inspectorate and its officials.

The Maritime Court is an independent tribunal.

The Water Police investigate all accidents occurring in Dutch waters, so that parties to the accident may be questioned. If necessary, one or more of those involved are also questioned by an official of the Shipping Inspectorate. If no official report is drawn up by the police, all those involved are questioned by this inspector, who then draws up an official report under oath.

At the end of the preliminary investigation, the Chief Inspector of Shipping is required to report his findings to the Maritime Court as quickly as possible. The findings include all the relevant facts about the ships involved and the crews, the log books, the charts used etc, and the statements of the persons examined. The report also carries a recommendation for or against further investigation by the Maritime Court.
A sub-committee of the Maritime Court decides how to respond to the report's recommendation. If the committee decides to investigate further, it names those deemed to have been parties to the accident and those who will be called as witnesses or expert witnesses. A party to an accident is anyone who could be subject to disciplinary action if they were shown to be culpable. Inquires conducted solely for their instructional value are attended only by witnesses to the incident and expert witnesses. If the committee rejects the report's recommendation, the Shipping Inspectorate may appeal to the Maritime Court. Procedures followed by the Maritime Court are described in section 4.3 below.

4 The Maritime Court

4.1 Composition

The Maritime Court is composed of a president and two ordinary members. The president must have a law degree; one ordinary member is a naval officer or ex-naval officer and the other a master or former master of a merchant vessel. For many years it has been the convention for the president and his deputies to be members of the judiciary. The Maritime Court also has a number of extraordinary members: shipowners and sea captains representing the merchant navy and the fishing industry, an ex-district head, a former captain of a pilot boat, a marine engineer, an electronics expert, a chief engineer and three naval architects. All these experts are nominated to the Maritime Court on the basis of their experience and standing in their chosen fields. Deputies are also nominated for each member.

Whenever the Maritime Court is convened, great care is taken to include any extraordinary members with relevant expertise, and to call any other witnesses and experts to give evidence in addition to the parties to the accident.
A secretary and deputy secretary are also attached to the Maritime Court, and they should also have law degrees. Members of the Maritime Court are appointed by the Crown for terms of four years, and may be reappointed. The Crown usually accepts nominations from the Court. The independence of the Maritime Court is thereby guaranteed.

In principle, no member -ordinary or extraordinary- is appointed for more than two four-year terms. Members have usually retired from the sea, and it is important that the body of knowledge available to the Maritime Court is as up-to-date as possible. It should be noted that the Maritime Court ensures that it keeps abreast of the latest developments by sending representatives on regular visits to port authorities, radar posts, survival centres, the hydrographic survey, etc.

4.2 Duties

The duty of the Maritime Court is to investigate shipping accidents. The definition of shipping accidents includes collisions, running aground, fires on board, stability problems, problems with dangerous cargoes, and industrial injuries to those on board.

The Maritime Court may take the disciplinary measures set out in section 4.4.

The safety lessons to be learnt from accident investigations are very important, as are the recommendations made in Maritime Court rulings.
4.3 Procedure

The procedure to be followed in accident investigations is laid down in the Ships Act and the Royal Decree of 17 December 1932, no 621, with subsequent amendments. Sessions of the Maritime Court are open to the public. Parties to an accident may bring their own witnesses and experts and specify the witnesses and experts they wish to be heard. Parties to an accident also have the right to be legally represented, and they or their representative may question witnesses and experts. Parties to an accident and witnesses are obliged to appear before the Maritime Court.

As a rule, the president and then the members of the court put their questions to parties, witnesses and experts. With a range of specialisms among the court members, all relevant aspects of the case are likely to be aired. The Chief Inspector of Shipping is also entitled to question parties and witnesses. The secretary draws up an official report of all statements made, which is then signed by the person questioned.

The Chief Inspector of Shipping then states his position, and advises the Court as to the disciplinary measures which should be taken, if any.

Parties to an accident and their legal representatives are entitled to be the last to speak. The ruling is then published in the addenda to the Government Gazette.

4.4 Disciplinary measures

Crew members with Dutch papers may be disciplined if the Maritime Court considers that they are to blame for an accident. The disciplinary measure may consist of a formal reprimand, or suspension of certification for a given period of not more than two years.
The same penalty may be imposed on a vessel’s master, if the Maritime Court upholds a complaint about his behaviour lodged by an interested party.

The Maritime Court may also declare certified crew members as unfit for duty, even in exceptional cases where no accident has taken place.

5 Statistics

The following table shows the number of preliminary investigations carried out by the Shipping Inspectorate in the last three years, and how many of these resulted in full inquiries by the Maritime Court.

<table>
<thead>
<tr>
<th>Year</th>
<th>number of preliminary investigations</th>
<th>number of Maritime Court inquiries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>129</td>
<td>24</td>
</tr>
<tr>
<td>1990</td>
<td>102</td>
<td>22</td>
</tr>
<tr>
<td>1991</td>
<td>103</td>
<td>25</td>
</tr>
</tbody>
</table>

6 Concluding remarks

The method of appointing members of the Maritime Court ensures its independence. The participation of the two ordinary members in all court sittings provides for consistency in the decisions reached by the Maritime Court. And the involvement of extraordinary members means that the Maritime Court always has any specific expertise it requires.

The president conducts the inquiry and ensures due legal process.
Parties to accidents and witnesses tend to cooperate willingly with the work of the Maritime Court, probably because like the president, members and shipping inspectors, they all speak the same nautical language.

The Maritime Court has the power to impose disciplinary measures on the guilty parties to an accident, and attaches great importance to it. At the time, the Maritime Court believes that the lessons which can be learned from its rulings are extremely important, and always takes potential lessons into account when dealing with or deciding on a case. The preventive role of the Maritime Court should not be underestimated.

There is no appeal form the decisions of the Maritime Court. The Ships Act does however contain provision for rehabilitation, empowering the Crown, having heard the Maritime Court, to restore a suspension wholly or in part, or to reduce its length. Against decisions of this kind there is a right of appeal to the Council of State, although it is almost never resorted to. Also, if new facts come to light in a case which resulted in suspension, the Maritime Court may reopen the case.

As part of its ruling, the Maritime Court makes a thorough analysis of the accident based on the evidence taken and the documents lodged, and gives reasons for its judgement.

Educational establishments, shipowners and other bodies use this information by subscribing to the Government Gazette in which the rulings of the Maritime Court are published.

The rulings of the Maritime Court are also discussed frequently in the trade and technical press, and lead not infrequently to amendments or supplements to the 1965 Ships Decree, the Notices to Shipping and the regulations of the International Maritime Organization (IMO), an agency of the United Nations.
A suggestion

Shipping is a global activity just as much as air travel. One of the tasks of the IMO therefore is to produce regulations which are binding on all seagoing vessels, of whatever nationality. This is not to say that there are not considerable differences in the ways in which different countries investigate and take action on shipping accidents. It might be a good idea to list these differences with the aim of achieving greater uniformity.

Amsterdam, September 1992
PROHOTIHG TRANSPORT SAFETY IN EUROPE -
THE ROLE OF THE EUROPEAN TRANSPORT SAFETY GROUP

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ABSTRACT

The need for an independent transport safety group which brings together professional and political expertise is outlined. The foundation of the European Transport Safety Group by three safety organisations - Deutscher Verkehrssicherheitsrat e.V. (Germany), Parliamentary Advisory Council for Transport Safety (UK) and the Raad voor de Verkeersveiligheid (The Netherlands) is described.

The aims of this new multi-disciplinary European group, which is in the process of being formed, are:

- to identify and promote research-based solutions to transport accidents with due consideration to practicality, acceptability and cost;

- to encourage common measures which will provide genuine safety benefits and lead to the adoption of best practice rather than the lowest common denominator;

- to encourage a wider awareness in the Community of the causes, effects and solutions to transport accidents;

- to identify priorities for transport accident research.

Introduction

It is a truism that road traffic deaths and injuries represent one of the major dimensions to twentieth century life and one of the most important public health issues at the present time.

On a worldwide basis about half a million people die each year. For every death there are at least ten people whom, at least by Western European standards, should be treated as in-patients in hospital. It is highly likely that this half a million deaths per year will increase to one million by the year 2000. This is largely, but not totally, because road accidents, like road traffic, represent a growth industry - particularly in the industrialising countries of the pacific rim and in central and South America. As far as
Europe is concerned, it is possible that things will also be somewhat worse in the year 2000. This is because the Mediterranean countries, particularly Spain, Italy and Greece still have relatively high growth rates in vehicle ownership. In some Eastern European countries, it is already becoming clear that the increasing levels of motorisation will pose many challenges over the next decade.

One of the interesting and encouraging phenomena of the last few years is a much greater recognition, both generally and at the political level, of the relationships between mobility, the environment and safety. Traditionally mobility has been the driving force of transport policy — solving the problems of efficient road use, building more roads, and using clever traffic engineering techniques to make saturated cities operate as efficiently as possible. But relatively recently the recognition of the substantial side effects of mobility, in terms both of environmental issues and traffic injury, have received greater attention. In many countries, more people now are beginning to question whether we have the appropriate balance between the three ingredients of this transport mix of mobility, environment and safety. Particularly in terms of policies for large cities, we are now beginning to see more adventurous policies on alternatives to the motor car, both on environmental and safety grounds, and greater consideration to alternative transport systems that redefine these three dimensions.

Transport safety in Europe

In the Single European Act there is a fundamental statement which says that "the European Community will be based on the free transport of goods, people, services and money between member states". Thus transport is at the heart of the aims of the European Community and much of the current debate on subsidiarity, we believe, will not really reflect on issues of transport because the free physical passage of goods and people is the essence of Community.

It is widely accepted that the social cost of 55,000 road deaths and more than 1½ million injuries each year in the European Community is too high. While deaths and injuries from other transport modes occur much less frequently, the serious consequences of individual tragedies continue to be a matter of public concern.

It is a fact, however, that safety issues do not yet form a central part of transport policy development in the European Community. The big battalions representing mobility have tended to drive transport policy and only after the general framework is set are the safety consequences considered. It
is vitally important that the safety dimension represented by safety professionals is considered much earlier on, and as an equal partner in the decisions that relate to modal choice, land use planning, the long term characteristics of city centres, and to highway and vehicle design.

It is also the case that in many parts of the European Community there is an absence of political will to recognise the drain that traffic accidents and injuries have on the Community. The problem of traffic safety has a relatively low political profile and, if progress is to be secured, then traffic safety issues must be pushed higher up the political agenda.

While substantial advances have been made in our understanding of the engineering and behavioural factors affecting the number and severity of casualties, it is also the case that progress has been inhibited by the general lack of good basic information about traffic casualties in Europe, especially non fatal casualties. There is too much emphasis on fatalities when, in reality, they form only a very small part of the whole traffic injury picture. We also lack data on the causes of accidents in the Community and their effects on road user patterns of injury. This is clearly an area where we must make progress very quickly to allow effective policies to be more easily determined and monitored.

There are thus two needs - to implement what we already know to be correct and effective and to increase our knowledge of the problems so that new solutions can be developed.

The European Transport Safety Group

To address these needs and to encourage common action which will provide genuine safety benefits, three safety organisations in Europe - the DVR in Germany, RVV in the Netherlands and FACTS in the United Kingdom - have come together to establish the European Transport Safety Group (ETSG), which grew out of the original proposal for a European Traffic Safety Council.

Status

The ETSG is being established as an international voluntary organisation to provide an independent source of advice on transport safety matters to the European Commission, European Parliament and, where appropriate, to national Governments and organisations concerned with safety throughout the Community. As an independent and non governmental organisation, the ETSG can cut across national
and sectoral interests in pursuit of transport safety objectives. It will bring together a wide variety of transport safety interests from across Europe including scientific, medical, engineering, transport user, specialist groups, trade and industry as well as Parliamentarians from all parties.

In the interests of independence the European Transport Safety Group will seek plurality in funding through membership subscriptions; conference and project income and grant income from a variety of sources.

The secretariat of the European Transport Safety Group will be based in Brussels and will become operational in early 1993.

Aims and objectives

The primary aims of the European Transport Safety Group are as follows:

- to identify and promote research-based solutions to transport accidents with due consideration to practicality, acceptability and cost;
- to encourage common measures which will provide genuine safety benefits and lead to the adoption of best practice rather than the lowest common denominator;
- to encourage a wider awareness in the Community of the causes, effects and solutions to transport accidents; and

- to identify priorities for transport accident research.

Membership and methods of working

Experience has shown that the efforts of a coalition of multi-disciplinary interests working towards a common safety goal can result in marked progress. The work of the Parliamentary Advisory Council for Transport Safety (PACTS) in the UK in relation to non-Governmental legislative initiatives on seat belt use and the introduction of road humps are examples of the successful partnership which has been forged between professional and parliamentary expertise.

Through the composition of its Board of Directors and the membership of its Main Council, the European Transport Safety Group will aim for a similar partnership. National safety organisations, transport user groups, medical
organisations, the police, engineering institutions, representatives from trade and industry, trades unions are, but few examples of the many potential contributors. Reporting to the Main Council, whose officers will be elected, technical working parties comprising internationally renowned experts will steer the course towards research-based policies and advice.

First actions

With road accidents contributing to over 90% of transport accident deaths and over half a million hospital admissions in the European Community each year, attention to research-based solutions to road accidents will be the Group's first and main priority. Its initial actions will be in pursuit of the following:

- to encourage the adoption of targets for reducing road accident casualties in EC countries;
- to identify and promote improvements to European vehicle safety standards; protective equipment and road safety engineering standards;
- to identify and promote best practice in education, engineering and enforcement throughout the Community;
- to recommend priorities for road accident research including recommendations on the standardisation of statistics.

The European Commission, following the report of the Gerondeau Committee, is now developing a long term programme aimed at reducing traffic casualties in Europe. The time is ripe, therefore, for an independent, private sector initiative to complement this Government sector activity.

The bringing together of Parliamentary and professional expertise is proving to be a successful institutional formula for expediting research-based solutions to transport accidents in the United Kingdom. We feel sure that it can make an important contribution to improving safety in Europe.
PLENARY CLOSING SESSION
SAFETY OF TRANSPORTATION; PRO- OR REACTIVE?

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The leading theme of this closing address is that transportation safety requires a re-orientation: the interest in safety of transportation shifts from component to system, from perceivable symptoms to underlying causes. This is an attempt to summarize a congress.

The objectives of recreating transportation safety science are:

first: the further dissemination of qualified notions, acquired in aerospace engineering, nuclear power plants, super tankers, offshore industry and processing industry,
second: a shift from feed-back from operations to an integrated approach both in designing and in operation.

I offer six elements for a further discussion on pro-active safety measures.

1. The current interest in safety issues originates in a long forgone past. Roads, railroads, shipping and aviation stem from different origins and have been seen as competitors from the beginning. Scientific interest focused on single modes and within these modes, towards the separate components of infrastructure, vehicles and operators. Safety solutions were aimed at the three e's: the separate areas of engineering, education and enforcement. The uses of accident investigation boards, casuistics and solutions, developed especially for aviation, shipping or railroads, illustrate how differently the approach has been compared to that of road traffic safety, where the emphasis has been on statistics and generic problems. In a few cases there is a sound reason for a different approach, in others not. Working conditions, accidental risks, the human factor and environmental issues have been approached separately, not in the least due to a partition in governmental supervision.

2. Novel transportation safety faces a discussion of widening the discussion, or not. Over the last 40 years, traffic and transportation have changed drastically. During the 50 - 60's emphasis was laid on the improvement of techniques, especially in aviation: with the automation of cockpit activities using micro-electronics and related to advanced design concepts such as fail safe, safe life and crash worthiness. In the 60- 70's the environmental issues of noise and pollution in road traffic and aviation emerged, as well as an impetus for town and country planning with such concepts as 'woonerven' (inhabited environments) and traffic mode separation schemes. In shipping and railroads modern encompassing technologies were also applied. In the 70 - 80's the interest in modality selection, costs and chain management such as 'Just in Time' and 'Door to Door' has arisen. Concepts such as Quality Control were introduced. In the 80 - 90's concepts such as 'Nederland Distributieland' came about in the perspective of internationalization, intermodal linking and major infrastructural projects such as TGV, Channel Tunnel and Main Ports.
As in large scale industry the interest in safety has been preceded by an interest in the environment, economics, quality control and technology. From the 90's on we shall see an increasing interest in disaster analysis, contingency planning and crisis management. Similarly, attempts to an integral approach of many other aspects are likely: environment, safety, cost-control, de-regulation, efficiency, public/private enterprises and the practical consequences of a concept as 'Sustainability'. Unfortunately, events during the last few years have taught us how serious the effects may be of under-estimating safety aspects. Examples are: Zeebrugge, Kings Cross, Piper Alpha and the Bijlmer/Amsterdam.

3. A review of the first day of our congress shows that safety considerations play but a modest role in what is actually developing. Safety measures today (especially legal measures) improve only by the feedback from practical developments. Moreover, this attention is aimed mainly at the micro level of the operator and his interaction with the system. Within each mode, faculty and design discipline, people think along different lines, although analogies are already clearly evident, especially in the fields of automation of the operators workstation, managing accident statistics, risk assessment, collision modelling and vehicle and vessel traffic services. The mutual learning process has improved and the in-depth knowledge of aspects is transferred; generalization on the lower levels of systems insight is in progress. However, at higher system levels, compatibility between transportation modes, town and country planning and traffic services is incomplete. If safety is to improve substantially, the consideration of safety aspects will have to:

a. follow the scaling-up of the developments in transportation: involve higher systems levels and consider complete logistic chains

b. introduce feed-forward coupling of safety requirements. The key words are: from correlation to causality, from frequency to consequence, from monitoring to modelling and control.

4. Consequently, safety must be associated with a systems approach to transportation.

There is a need for:

a. expertise and skill with respect to safety as a system

b. the weighing of safety issues in probing for an acceptance of solutions.

ad.a There is a need to elaborate a professional safety component in transportation. Safety science must develop insight into the processes themselves, must foresee possible effects before damage and injuries occur, must mitigate the effects in case of an accident, must associate safety aspects with design and operation and link with more integrated views on traffic and transportation processes and multimodal transport chains.
There is a need, especially in the long run, for social weighing and acceptance of technological developments, due to their extent, nature and life cycle duration. Decision making and control, inherent to these developments, will create new disciplines: policy analysis, a decision supporting information technology and an engineering design methodology. Safety should be incorporated in these developments: the process component in decision making should be strengthened.

5. Fixed starting points for the development of transportation safety, additional to existing efforts, have been given during the second day of our congress. Addressing four such starting points:

1. to incorporate safety as an explicit aspect in the conceptual change of transport systems for the 21st century. Universities of Technology like Delft Institute of technology have a preeminent task in the conception of new systems and in the education of people who are able to design, construct and control these systems and who are able to bring the various, often conflicting interests to a synthesis. Our Chancellor will in a few minutes certainly comment on this.

2. to express in the solutions an integrated approach to the problem. It took 50 years after the rationalization of labour to humanize working conditions again. It took the expenditure of a fortune at a well-advanced phase of the closure of the Oosterschelde (one of the Dutch estuaries) works, to save the environment. It seems that the selection of a route for a cargo rail track in close proximity to the urban areas of the Betuwe region (of which I spoke yesterday at our dinner), will sacrifice the needs of the human population. There should be no dominance by one aspect or transport mode, but an optimization process, in which all aspect are weighed and incorporated; including environment, working conditions, safety and sustainability.

3. the development of new research techniques with two requirements:
   - separate the accident research for learning purposes from the inquiry into the liability question and create a common basis for all modes in such accident research
   - prospective approach. Increase by this accident research the predictive potential for other foreseeable accidents, before damage occurs

4. interest in decision making processes on a social level. A certain consensus between stakeholders is required due to the costs, life cycle duration and the huge consequences of large scale endeavors. Dominance of one stakeholder or one aspect is counterproductive in the long run, because it hampers a balanced decision making.
A consequence of all this assessment of safety during the decision making is only possible if control on forehand by one stakeholder is absent. Experts should be relatively independent in order to maintain their credibility and reliability. From the nuclear power, processing and aviation industry we have learned that a thorough knowledge of those complex and major activities is indispensable for their accepted existence. Therefore, accident research and research into the possible effects of new developments must be based both on expertise and on independence. Only then is a social basis feasible on the long run. An international organization to this aim has a right to exist because within it, expertise can be combined with independence.
CLOSURE OF THE CONFERENCE

C. Boerman
Delft University of Technology, The Netherlands

Ladies and Gentlemen,

At the closure of this congress I would like to refer its opening, when the Rector Magnificus compared the issue of safety with the introduction of the working conditions legislation in 1890 and the role of the Delft University of Technology. He considered the situation from a scientific and educational point of view, but from a more general standpoint, there are also parallels to be drawn. In those days when there was the social issue of the quality of labour in agriculture and manufacturing. We now have the issue of the safety of transportation. In 1888, a Parliamentary Hearing brought the subject into public debate in the Netherlands. Today a number of major accidents all over the world are topical and of public interest: Piper Alpha, Zeebrugge, Kings Cross, Breda, Mexico City and recently the Bijlmer airplane accident. Now, as in former times there is a broad social support for change. At this congress various Transport Safety Councils have expressed their opinions, members of the Dutch Parliament have given positive signals, the Commission of the European Communities has sponsored the congress and experts agree that there is an urgent need for change.

As in former times, developments overseas have preceded events in the Netherlands. As in those days environmental issues are preceding safety issues. The first Royal Decree on environmental protection was signed in 1824 whereas the Safety Act for factories was issued much later, in 1890. Now, as in those days experts, independent experts are required. In 1890 the Labour inspectorate was founded, today we are requesting close cooperation between independent accident investigation councils, supported by experts in various fields. Again as in the past, there is today considerable room for innovation and effective solutions.

Looking back at history, at a century with long and sometimes fierce discussions, we now all conclude that these developments have been a blessing, beneficial for everyone. Hopefully this will also apply to future developments regarding transportation safety. It would be a disgrace if, after a number of years, we would have to conclude that another Parliamentary Hearing, now on transportation safety, would be required to ensure acceptable levels of safety.

For me, from a managerial point of view, the questions are: how can management facilitate all this? How can the sum of all parts be more than a simple addition. What can we as a university contribute? Delft University of Technology is willing to play its part, together with other research institutes. We are looking for close cooperation with many stakeholders, because the challenge which we are facing, is both considerable and of an international nature. It will require team work to succeed. Delft University of Technology covers all relevant basic disciplines. We are in a position and prepared to form or participate in working groups, both internal and external. Within our university we founded Ditrail, the Delft Institute of Transport, Infrastructure and logistics and during this congress valuable relations were established with other research institutes. Representatives of these institutes were present at this congress. TNO.
and SWOV have actively participated in the organization of this congress. It demonstrates that transportation safety is not only a scientific challenge, but a social challenge as well.

In the development of a strategic policy for our university, safety of transportation is an important issue; a challenge to be met in cooperation with government, industry and research institutes. We accept this common challenge.

With this statement I now formally declare this congress closed.