The human paradox in technology and safety

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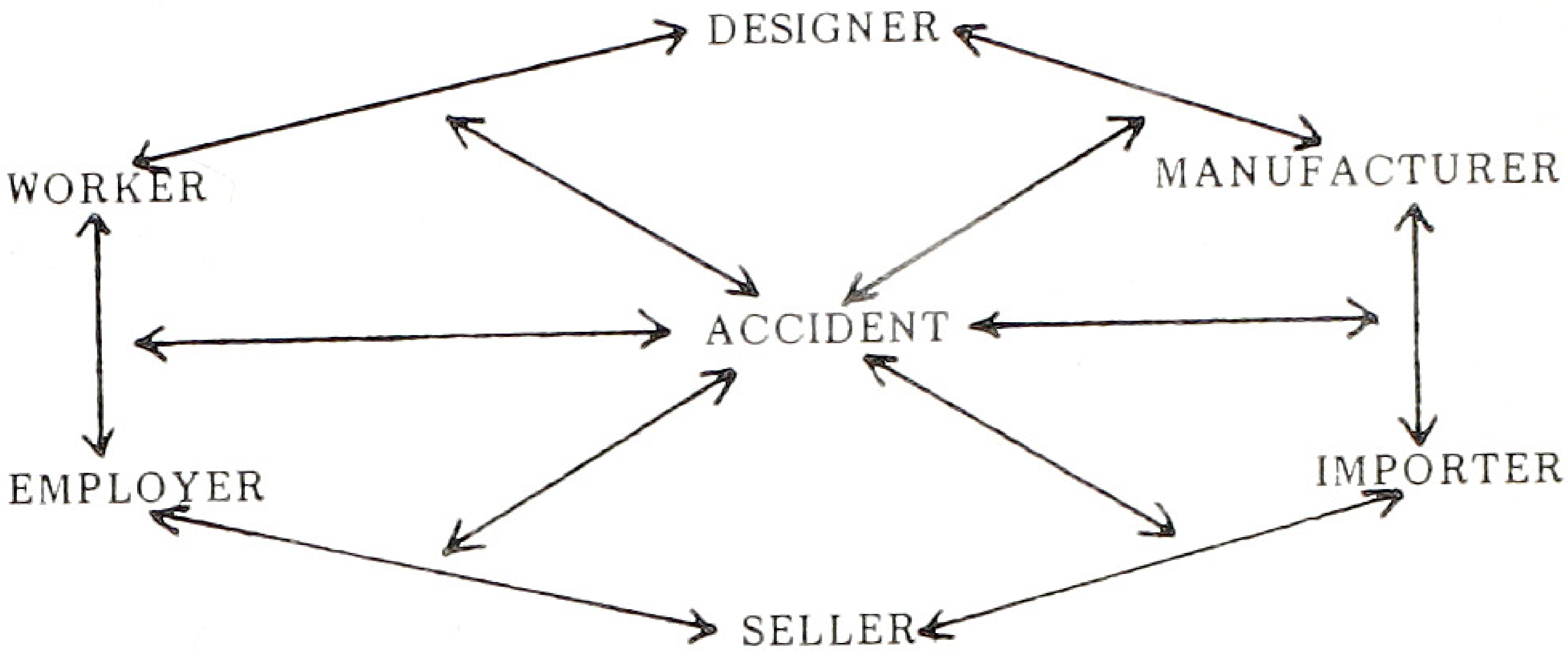

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Inaugural lecture
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THE HUMAN FACTOR AS CAUSE AND SOLUTION

In 1972 the Confederation of British Industry, in giving evidence to a Royal commission on the future of the safety laws and their administration, summed up a point of view which has a long history in the field of safety. "The root of the problem is human behaviour" they said, and went on to talk about the need to engender a sense of responsibility and of duty in individuals to take care of their own and other people's health and safety. (1)

Early British factory inspectors voiced a similar concern with human behaviour when deciding their policy on the reporting of accidents in the middle of the 19th Century. They considered it only relevant to learn about the small proportion of accidents which involved machinery, since they regarded the rest as the result of the vagaries of individual behaviour, and so unpreventable by any practicable means. (2)

In the standard texts on safety which appeared from the 1920s onwards an almost invariant inclusion in the first chapter were figures such as "80% (or even 90%or 99%) of accidents are due to human errors, or other non-technical causes" Such texts,containing what came to be known as the 80:20 rule were typically written by people with an engineering or pure scientific background. They were sometimes answered by texts written by social scientists which put the figure much lower, at around 50%. However even those coming from social science backgrounds accepted that by far the largest group of accidents fell into their area of expertise. The language of these texts is very much the language of unicausality and of carving up the problem for solution: if the causes were seen as technical then the solutions must be technical; if the causes were human error then something must be done to the humans. (3)

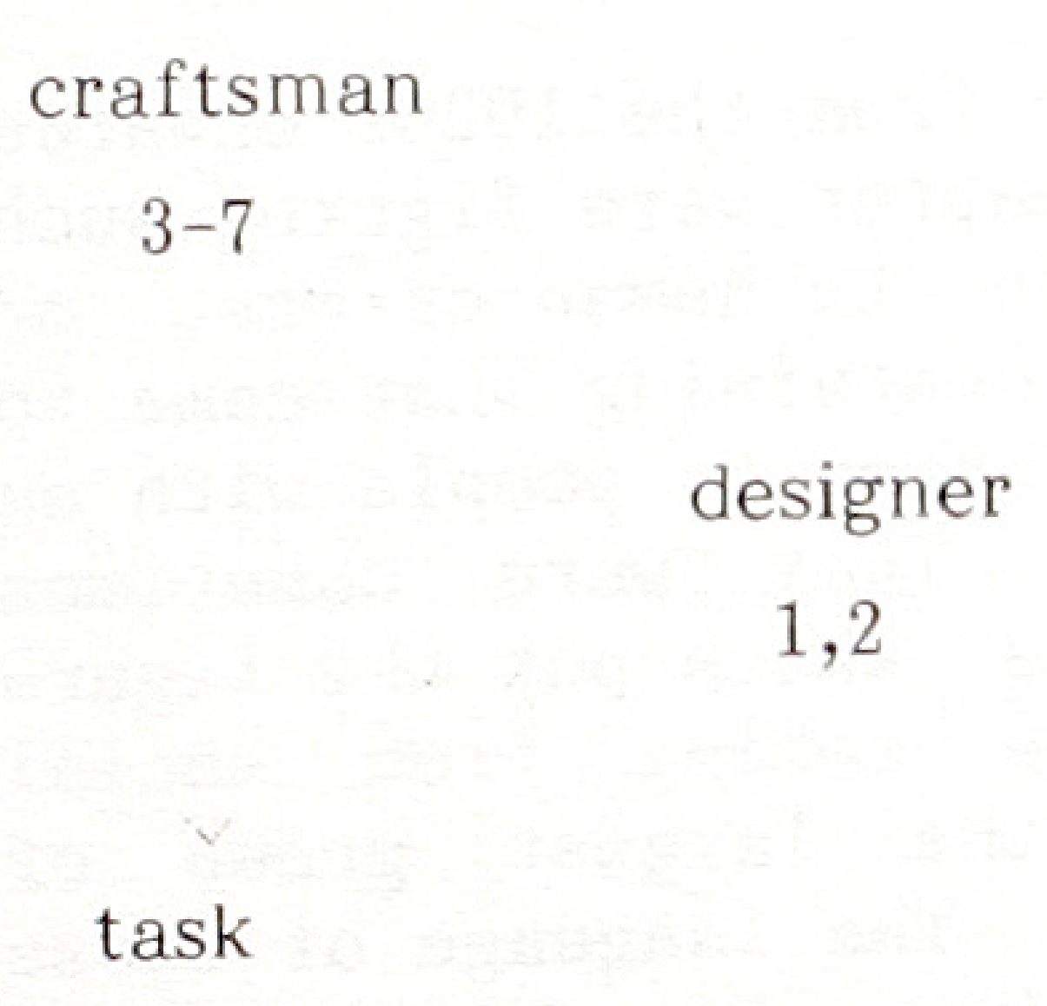
The dominant lines of research and theory proceeded in the 1920s and 1930s in the technical and social sciences more or less independently, but they shared a common theme. Both wished to eliminate humans from the danger situations; only the means of doing so differed. The psychologists took the problem away and incorporated it into their programme for development and use of psychological tests. They looked for the ways of predicting in advance those who fitted into what they conceived of as a relatively small group of individuals who were more prone to accidents, and so selecting them out of dangerous work. However, that tradition, after 40 years of work produced almost nothing for industrial safety and only a small contribution to transport safety.(4) Making errors proved to be far too much a basic part of the way in which humans worked for it to be

DIVISION OF TASKS BETWEEN MAN AND MACHINE

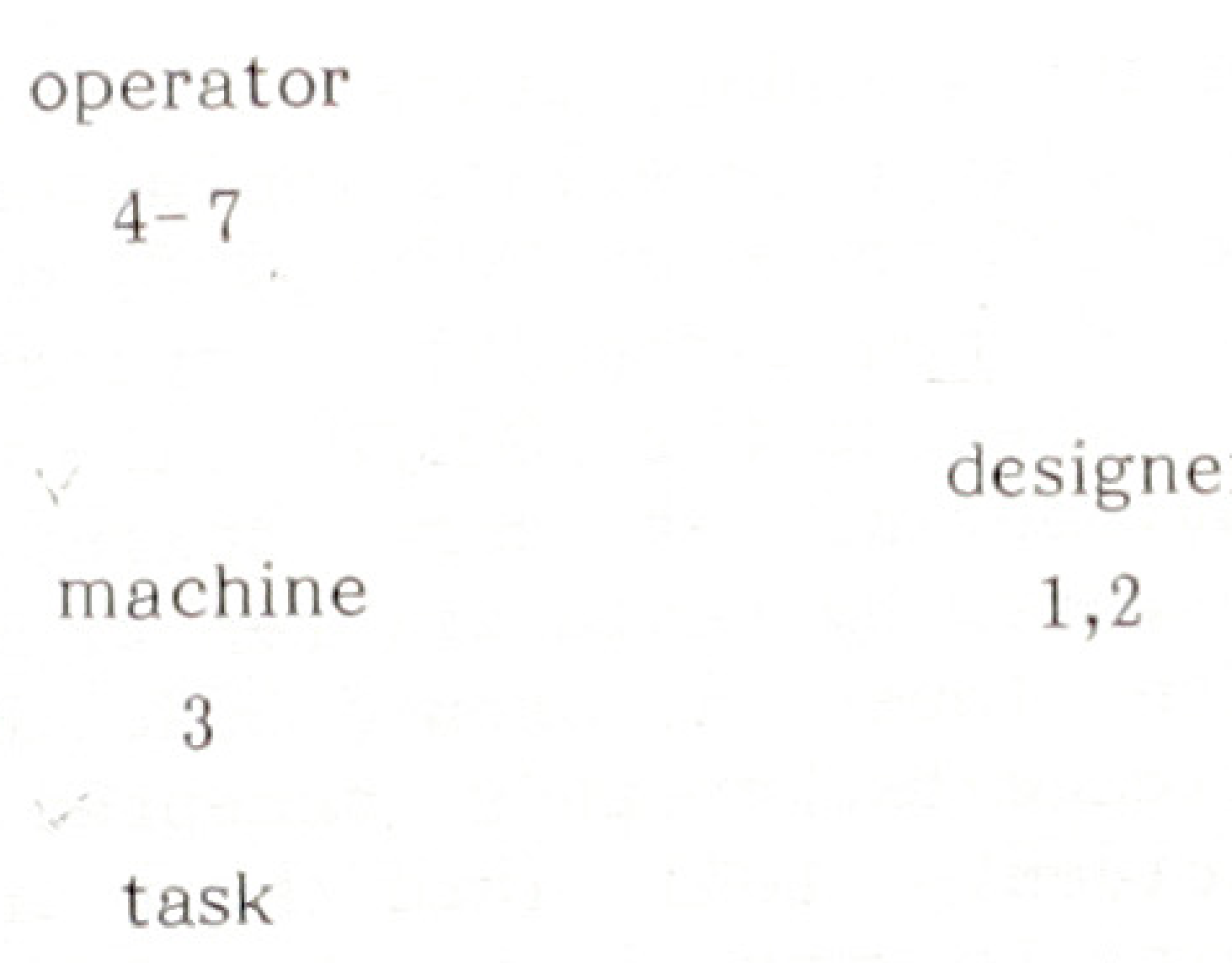
(After Singleton, /5/)

1. Specification of Objectives
2. Design & Manufacture
3. Provision of Power
4. Routine Operation
5. Programming of Smooth and Appropriate Operation
6. Monitoring and Diagnosis of System Failures
7. Maintenance and Repair/Emergency Intervention

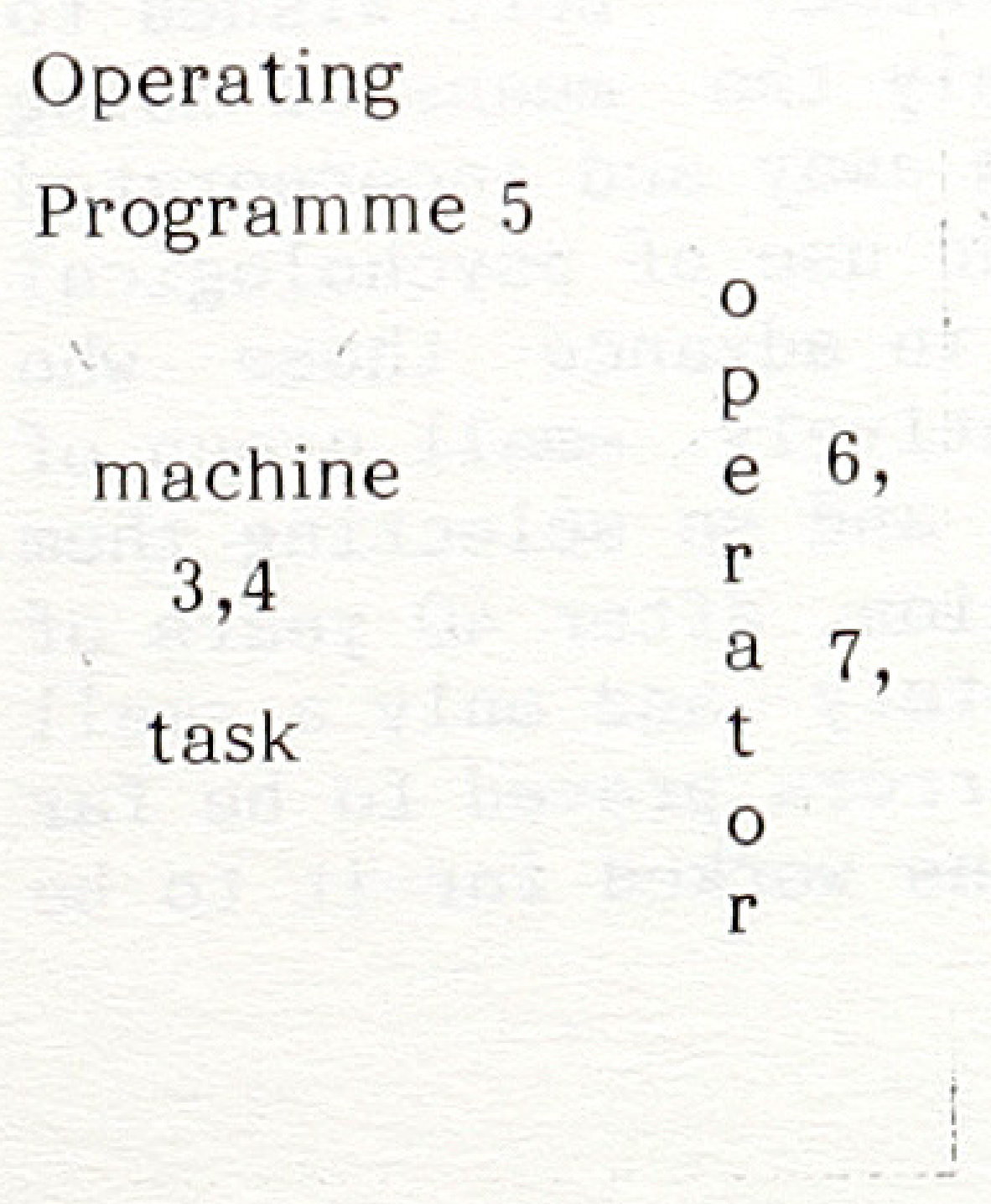
1. Craft Skills



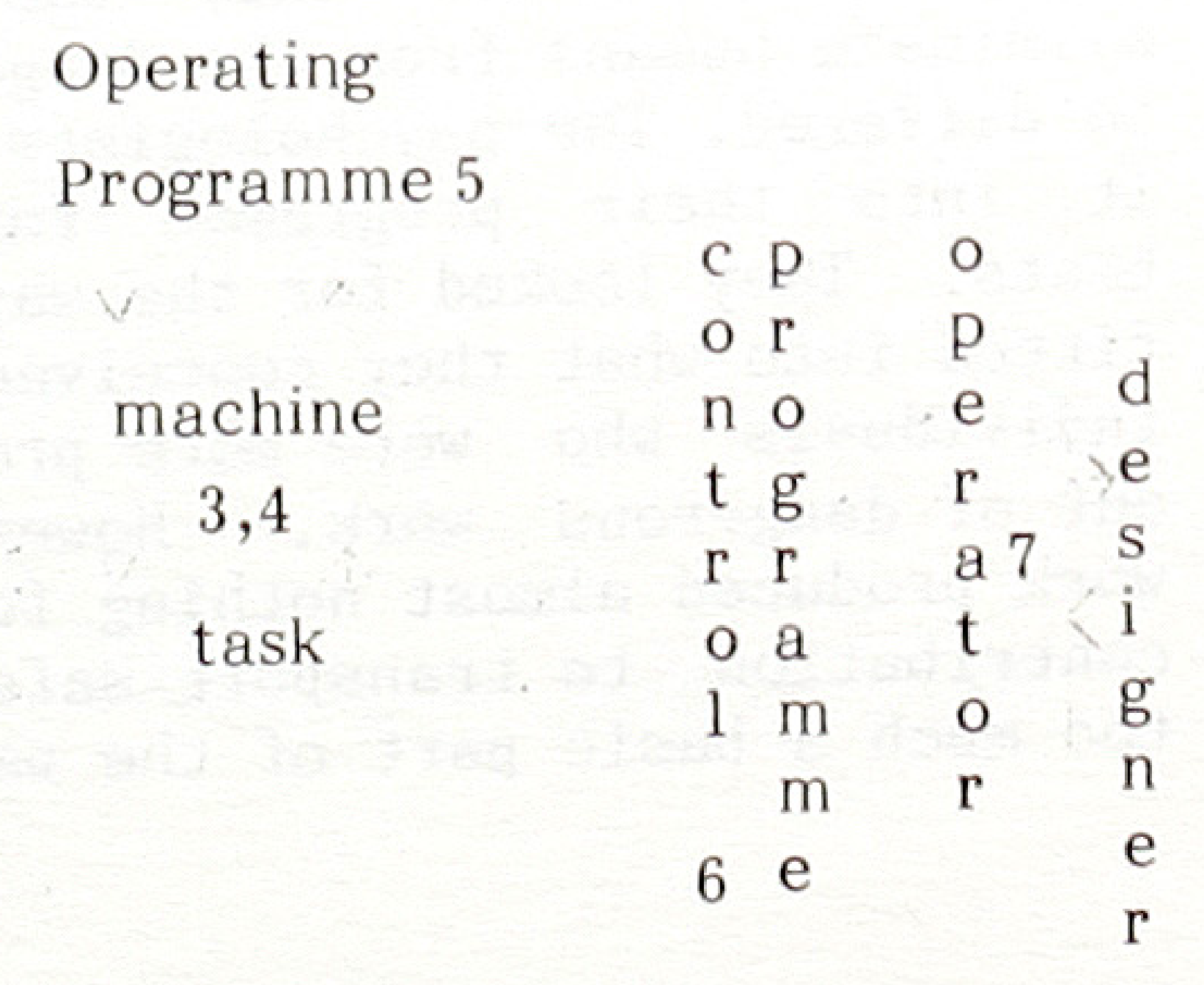
2. Machine operation/ Mechanisation



3. Automation/ Machine-minding



4. Emergency intervention



isolatable in a few "accident-prone" individuals. For the engineering sciences the problem became intimately wrapped up first with mechanisation of work and then with its automation. As humans were replaced by the more efficient machine as a source of energy and later as a source of control, so, consciously or more often incidentally they were removed from some of the roles in which they had previously been the victims of accidents or of work overload.

With manual work and skilled craft work people had carried out all of the tasks, from deciding on the objectives of the task, designing and building the tools, providing the power to drive them and the skill to guide them, monitoring the actions they made and putting right any errors. In the course of time, first the provision of power was consigned to the machine, leaving the person as the driver or operator; then the control was handed over to multitask machines, numerically controlled, and finally computer controlled machines, leaving the person as a machine minder in a monitoring role; then this too was taken over by automated monitoring programs leaving the human only to diagnose and intervene in emergencies. (5)

Accident figures showed a slow but general decline in frequency rates, per man hour worked or per kilometre travelled, although this underlying decline was sometimes hidden, e.g. in transport accidents, by the greater increases in the numbers and/or time at risk. Also the size of the energies locked up in mechanised and automated technologies and their complexity meant that the effects of an accident when something did go wrong were more dramatic. However, the analyses of the accidents which continued to happen still showed that "human factors" dominated as a cause. As fast as humans were eliminated from one accident scenario they crept back in another guise in others.

PROBABILISTIC RISK ASSESSMENT

An illustration of this trend can be seen in the design of safety systems in nuclear power plant. The development of this technology from its inception took place with constant awareness that the energies locked up in the power plant must not be allowed to escape. The increasing awareness of the effects of small doses of radiation drove the industry to develop more and more sophisticated safety systems. Hand in hand with the aerospace programme many advances were made in reliability analysis and the design of highly reliable plant. Probabilistic risk assessment techniques based upon detailed modeling of the plant dynamics, and upon expanding data banks of failure data for the plant components lead to greater and greater accuracy of prediction of technical failure and of design against it. (6) As part of this drive more automation was brought into the control room to hand operator control and monitoring tasks over to the technical system.

The apparent progress in improving the predicted safety of plant was rudely shattered by the accident at Three Mile Island. There an operator misdiagnosis resulted in incorrect control action being continued for a period of over 2 hours and in a partial melting of the reactor core. (7) Another example of a similar type occurred in W. Germany at Brunsbuttel, where operators disabled safety equipment in the interests of maintaining electrical supply, and so allowed a leak of radioactive steam to occur. (8) In still other examples maintenance personnel at Brown's Ferry improvised a candle as a means of testing for a gas leak in a cable duct and caused a major cable fire, and at another utility tried unsuccessfully to use a basketball to block a pipe during maintenance (9). This brought into sharp focus cognitive errors of commission where people acted not like technical components, but as active planners (in this case erroneous ones) The result was a redoubled of efforts to eliminate the human. Thus in the safety case made by the Central Electricity Generating Board for permission to build the first PWR in the UK considerable emphasis was laid on the fact that the reactor would shut itself down automatically after a loss of coolant accident without requiring any intervention from the operator for the first 30 minutes after the incident. (10) Critics pointed out in the Public Enquiry held to consider the planning application that this only eliminated operators' errors of omission from consideration, not incidents, such as TMI, where operators intervened positively owing to incorrect diagnosis to frustrate automatic shutdown procedures. It was suggested that, if plant shutdown could indeed be achieved in all cases without human intervention, it would seem logical to lock the operators out of the system during that half hour. (11) This the authority was not willing to accept, citing as one reason that there were still eventualities, both foreseen and unforeseen where it would be advantageous if the operator could intervene to improve upon the performance of the automated systems. It was also accepted that unforeseen situations could occur beyond the design base of the automatic system, where the human would be the final line of defense. In making these points they laid great stress on the high level of qualification and experience of their operators as a guarantee against wrong actions.

In these statements I believe we come to the crux of the human paradox in technology and safety. Even with the greatest expenditure of money we cannot, or perhaps are finally not willing to root the human being out of the system entirely. Labelled as he or she may be as the major cause of accidents and the major problem which the technologist has to deal with, still the human being is seen as an essential element in the solutions to those same problems. And if this is true for the multi-billion flagship of the high-technology fleet, nuclear engineering, how much more true is it of other technologies. What is more important is that just those characteristics which sometimes lead to error are also the ones on which smooth system functioning relies to overcome the shortcomings of the technical system; to tap the pressure gauge when it gives an anomalous reading to check that it is not stuck, and not automatically to go into an expensive shut down; or to improvise new ways of driving the plant when crucial equipment is out of commission.

This naturally generates feelings of mixed frustration and helplessness among technologists, whether researchers, designers or engineers, who see a crucial element in the success of the system

for whose design and running they feel responsible as outside their cognizance and competence to predict and so to control. Such feelings can also be seen reflected in the answers given by the departments of this institution to the circular sent to them last year by the Safety Science Group. That circular asked which areas they felt to be ones in which they most needed a contribution from the group. By far the commonest response was the role and control of the human factor in one guise or other. (12) In this I see the mutual recognition of an important part of the field in which safety science can contribute to the technical disciplines.

EXPERT JUDGEMENT

I want to stay for a moment with high technology industry and with PRA, in order to draw out another strand of my argument. I have mentioned the use of data banks of failure probabilities as a part of the quantification process for PRA. Their purpose is to provide data from real conditions of use for the probability and length of time to failure of components of plant (valves, relays, pumps etc). Once histories of large enough populations of the same components used in the same conditions have been gathered, valid and reliable estimates can be made of the probabilities of failure of elements. These can then be built into calculation of the aggregate probability of a given top event failure in a fault tree. Even with technical components it is a major task to build up data banks large enough to cover all relevant types of components working under all relevant conditions of temperature, pressure, corrosiveness of atmosphere etc, and under representative regimes of maintenance and use. To fill out the gaps in the data bases resort has to be made to "expert judgement" to decide how the data available should be transformed for any given specific use. (13) Such use of expert judgement is commonplace in all design work by engineers. Theory and data give only a standard norm which designers must interpret for each specific use.

The first response to the realisation of the importance of the human factor as an element in fault sequences was to call for comparable reliability data bases for human actions. Indeed some such bases were assembled. (14) It may seem surprising in view of the prospect of many years of well-funded research that the Human Factors Society that approach as "while theoretically possible, practically infeasible." (15) The very versatility of the human makes it impossible to treat it as a component in the same way as a pump, or even as a computer. The number of environmental as well as personal factors which significantly alter error likelihood is far greater than for hardware components. What is more important, however, is that human "components" are sentient and adjust their behaviour according to the predicted outcomes of a situation. A valve will not differ in its behaviour if its operation will result in radioactive steam being released safely to a cooling tank or unsafely to the open air; a human will certainly behave differently if he or she believes that an action could have the latter, disastrous effect. In addition, though humans have a high basic error rate they are also good at detecting their own errors and recovering from them before they produce harm. (16) Modeling this in an error data bank is very difficult.

Frustrated in the search for simple human error data banks the PRA community again turned to "expert judgment" as its salvation. With the convergence of concern in both technical and human reliability upon this same element of expert judgement, the spotlight focussed on the human element in another guise. Sadly for the peace of mind of the designer the research literature shows that the accuracy of predictions made by experts in a range of fields is patchy (17). At best, e.g. with weather forecasters predicting rainfall, the expert is excellent; at worst, e.g. financial analysts predicting stock market prices, he or she is little better than the amateur. There is now a burgeoning research field driven by safety science concerns which surrounds the use of such techniques. In the field of judgements of probabilities the psychological literature on decision making can make a great contribution. It shows that, while a whole range of biases and errors occur in specific circumstances, many of these are systematic, and so can be allowed for or countered, and at least some are open to correction by training in the relevant statistical concepts.

MENTAL MODELS

What is also clear from that literature is that one of the most crucial elements in the accuracy of judgements is the knowledge that the experts have of the underlying mechanisms which they are trying to predict. In the field of human factors this has lead to a great flowering of research on the mental models which experts have of the causal network of events whose probability they are trying to predict. (18) In parallel studies are also under way of the mental models which operators have of the plant they are controling and the ways in which it can go wrong (19). This concern with mental models has also developed in parallel in other spheres. In the field of artificial intelligence the new discipline of "knowledge engineering" concentrates on modeling the decision processes of the expert so that they can be built into expert systems which will be capable of diagnosis and judgement in uncertainty. The mental models that microcomputer users have of the software they are using is being shown to be a crucial factor in the errors they make when using new programs. (20) Those of you who have your own micros will know what I mean by mental models if you think back to the number of times you have talked to your machine as though it was a naughty child when it did something wrong (note that it did wrong, not you), or if you realise that the reason that you lost a file from memory while copying from one disc to another was that you did not picture the information going through memory to get from one side of your dual disc-drive to the other. Exploitation of our growing knowledge of these mental models enables system designers to build more user friendly, and so less error-prone systems which use the operators' models positively, rather than forcing him or her to conform to the designer's own, usually very different, mental model.

In the field of information and training to deal with the more everyday chronic hazards of chemicals, noise, manual handling etc. (21) I have shown that the same concern to understand the mental models workers have of their tasks and of how harm can occur to them can provide new insights into problems that have frustrated several generations of those concerned with safety. This theme is already a central one to the research of the Safety Science Group, with our concentration on studying the way in which all concerned with any hazard view the problem and its solution. I see it as a major area for our future development. It is already reflected in one newly funded project on the use of expert judgement of probability in the high technology field. It will also form a major part of projects we are planning in the development of interactive computer systems for the collection and analysis of accident data. A longer term development is to study the way in which information about hazards and their control can be presented to designers through integration, for example, in CAD systems, so as to fit with their mental models of the design process. On the health side of our subject there is great potential for using this knowledge of mental models to present information in better ways to people who have to work with those hazards.

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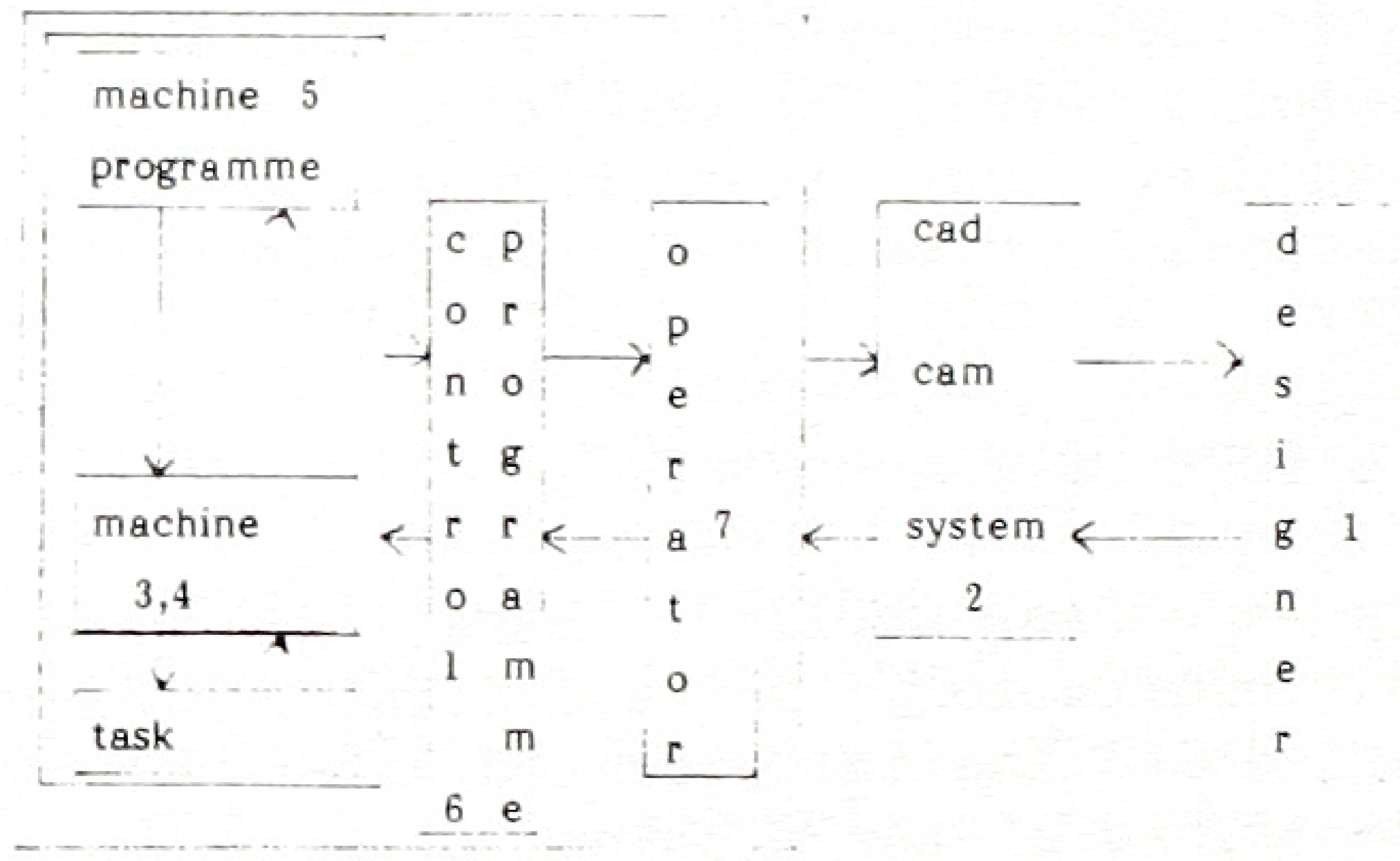


THE NEED FOR INTEGRATION

I want to draw a number of interim conclusions at this stage, and to make some assertions preparatory to the next stage of my speech;

1) I have shown that, in the examples which I have taken and indeed in all other technological systems technical and human factors are inextricably linked together in succesful system functioning. The human factor has no meaning divorced from the technology, since the men respond to the technology and the technology to the men. No attempt to suppress completely one or the other element can possibly succeed in achieving optimum safety. What is required is to capitalise on the positive features of both.

2) There exist within the individually relevant disciplines of both technical and social science many research findings of relevance to the solution of these safety problems.

3) Because of the structure of the education system and of the division of labour between disciplines and between professions those insights are habitually separated, and indeed each side often denigrates the potential contribution of the other.

4) The coordination of these potential contributions requires

techniques of analysis and models of system functioning which can span these disciplines and integrate the insights they offer.

5) These techniques and models centre upon the interaction of people, technology and the organisation of society (procedures, laws, management etc).

6) These are the tools of the trade and the work area of Safety Science.

COMPLEXITY AND RESPONSIBILITY

At this point it is perhaps apposite to quote one of my predecessors at the University of Delft within this broad field of safety science. In 1907 Dr L Heijermans, in opening the first course in "social and technical hygiene" to be held in the Nederlands said; "The future engineer, the technologist, the aspiring labour inspector are taught as completely as possible the solutions to the difficult technical problems that they will meet in their later life. They learn well the construction of bridges, the laying of roadways, the development of mines and the statutory regulations which must guide their behaviour; however, in their practice in the outside world, as well as iron, stone, ore and law they meet also men, with whom they must collaborate, whose tasks they must prescribe, and whom they must oversee in all respects." (22) It was Heijermans' aim to bridge that gap through his teaching, as it continues to be the objective of his distant descendants myself and the existing Safety Science Group.

THE MULTIFACETED NATURE OF THE PROBLEM

Exactly 75 years ago Prof Dr. J.G. Sleeswijk gave his inaugural lecture to this institution, as the first professor in Technical Hygiene. He entitled it "The multifaceted nature of hygiene".(23) To illustrate this he talked of the problems of workload and fatigue and the insights offered into them by the developing techniques within physiology, biochemistry and immunology. He saw this not just in terms of physical workload of such work as bakers or miners, but, in a passage with a very modern ring, prefigured the much greater present day concern with mental stress. In commenting on the fact that his statistics told him that the life expectancy of doctors, engineers and architects was below that of bakers, he first of all named alcoholism and venereal disease as no respectors of social class or profession, then pointed to the dangers of overeating, and finally said: "And you can be sure that most of us who, our day's work acheived, spend the evening and some of the night in strenuous mental activity, place a load on our nerves and blood systems which is in no wise less than that which the average manual worker must suffer.

His second example showed the role of new developments in technology in changes in health problems. He talked of the carriage of infectious epidemics across the world because of the revolution in the speed of transport; of cholera from Russia by ship, or by the Hejaz railway from Mecca. He called on the "engineer as auctor intellectualis of modern transportation" to pay attention not only to the development of the railway, but also to collaborating with hygiene authorities to ensure that public health concerns and checks on passengers were built up as an integral part of it.

ATTITUDES TO TECHNOLOGY

These quotes show the breadth of the vision which Sleeswijk had of the interaction of technology, society and health. We are still busy with many of the same problem areas, although thankfully we have gone a long way to solving many of the specific aspects which concerned him. However, in one important respect his rede does not read with that modern ring. He has a springing optimism for progress and for the contribution of science and technology as an essentially positive force. At one point he says this: "Rapid transport has created the conditions for rapid emigration, and that same transport ensures a similar distribution of food over the whole civilised world. An incalculable area lies still fallow and there is space yet for many. And what shall the chemical industry with her synthetic products yet be able to contribute to the fecundity of the soil? It seems to me as fruitless to examine whether the human race will eventually die of general starvation as to calculate when our far descendants will succumb to lack of light and warmth from the extinguishing of the sun." We live now in a world where the open spaces are no longer available and where such calculations no longer seem so premature.

The great change has been that we are much more aware now of the finite nature of the world's resources and the importance of their conservation. With that realisation has come also, ironically through that very chemical industry and its synthetic products in which Sleeswijk placed his optimism the realisation of the complex interactions between one part of our world system and another. Chemicals, such as pesticides, which play a vital role in increasing productivity in one sphere accumulate in other spheres, remote in time and space, to become threats to the health and lives of the people whom that productivity keeps alive. This developing understanding of the complexity and interrelatedness of the world and its systems can also be traced in our views about safety; about where the problems lie, whose they are and who can and should be responsible for solving them. The law is a convenient mirror to hold up to trace those changing concepts, trying as it does to capture and crystalise society's views of responsibility in a codified form.

Lest the word "responsibility" mislead you into thinking that I am about to take a moral stance on safety, let me hasten to disillusion you. The sense in which I want to use responsibility is a very practical one, linked closely to "who does what": who studies and researches safety problems; who teaches the results of that research and to whom; who decides upon standards, norms, rules and procedures, who chooses solutions and who pays both for the prevention and for the damage to people and things which comes when the prevention is not undertaken.

THE CHANGING VIEW OF RESPONSIBILITY

In the 19th Century the prevailing view held by both Dutch and English law was that the individuals' safety was very largely a matter of their own responsibility and free choice. Workers were held to be free agents who knowingly accepted the risks of the jobs that they took on. If they did not like the risks they were free to go elsewhere. Thus their safety was their own affair, and they must bear the costs if they became injured. So strong was this belief that government legislation interfering in this "contract" had to be explicitly justified on the grounds that the group to be protected were, for some reason not free agents.

"When these acts were conceived, they were regarded... not as measures for the improvement of industries to which they applied - as they have since very largely proved to be - but merely as acts of police, designed to prevent particular offences of oppression by employers against helpless individuals of such defenseless classes as women and children." (24)

However the reports of the British and subsequently other labour inspectorates showed that the doctrine of "free contract", which supposedly protected the rest (i.e. the male part) of the workforce, was a pious sham. Only then was the way opened for accident insurance and compensation for injury. These developments, which were brought about in most European countries around the end of the 19th century, depended upon the acceptance that the workers could not be held entirely responsible for their own accidents; that their behaviour was constrained by the pressures and conditions under which they worked and therefore the employers were also strongly responsible for, and should pay towards the resulting compensation. What had previously been seen as an aggregation of independent and self- contained individuals had now come to be seen as a simple interconnected system, with mutual responsibilities. But that interlinking was very limited. In the case of damage or injury caused by a machine bought by the factory owner, the responsibility lay with the buyer not the seller. Similarly the customer in the shop had to bear the responsibility for buying an unsafe product. The concept of caveat emptor (let the buyer beware) expressed the belief that both sorts of buyer were free agents in the face of the seller. Under the Burgerlijk Wetboek in Nederland and under the Common law in Britain there was some protection against knowingly faulty or dangerous products, but it was extremely difficult, if not practically impossible, for the injured party to prove the necessary guilt on the part of the producer.

THE RESPONSIBILITY OF THE RESEARCHER, DESIGNER & MANUFACTURER

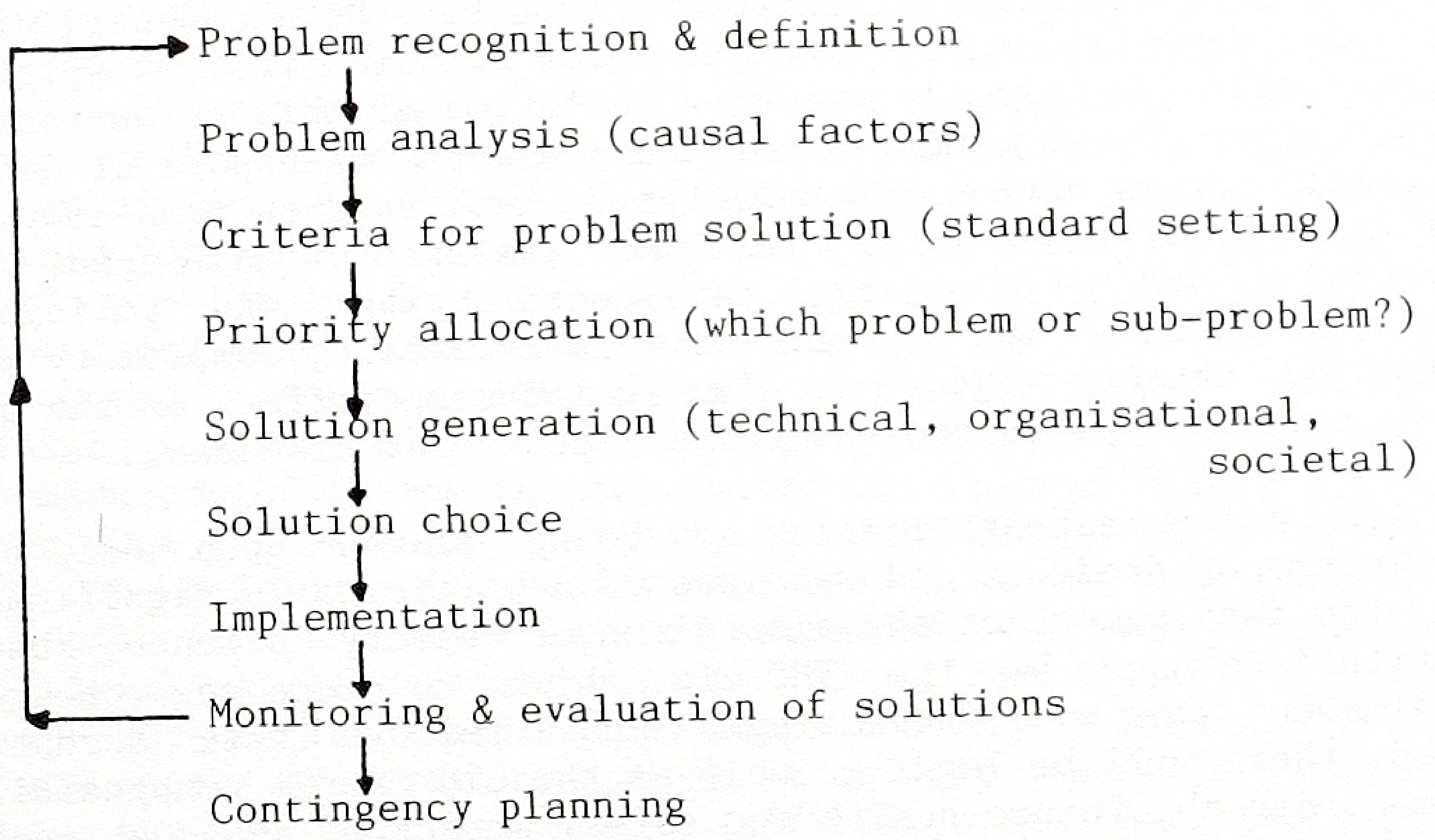
The third stage in the recognition of complexity and interconnection has come with the increasing acceptance that the designer, manufacturer, importer and seller must bear more responsibility for the safety of their product. This has come about in different countries with differing speed, and usually in industrial safety before consumer or transport safety. The legal signs of this can be seen in the reversal of the burden of proof, so that the injured party only has to show that injury was caused by the product, whilst the maker or seller of the product must now prove why he should not be held responsible for that damage. This has been followed, in some countries by specific laws allocating the responsibility to designers and manufacturers. They must carry out research to discover the dangers of their wares, to make them safer, and finally they must inform their customers of the remaining dangers they are buying and the precautions they must take to avoid those dangers. Parallel developments have taken place in the responsibility of companies for environmental pollution and in the professional liability of experts for the damages caused to people by following their advice. The huge damages awarded in malpractice suits against doctors in the USA are perhaps the most extreme flowering of this development; but in many other countries, including Nederland, the insurance companies are becoming increasingly alarmed at the size of the payouts to be made on behalf of those designers, producers or experts following disasters such as Bhopal, asbestos or thalidomide. (25)

It is not my purpose here to discuss further the rights and wrongs of such legal developments. I merely want to point to the trends as evidence of society's wish to make ever more complex links in the search for the location of responsibility for the accidents, diseases and environmental damage which occur within it. A development increasingly discernable is the escalation of this to supranational levels, over issues such as acid rain and the transport of dangerous materials across national boundaries. Each further push complicates the network of responsibilities, the numbers of different groups involved, and the task of coordinating and policing the responsibilities. The pay-off for this increasing complexity must be judged by whether there is also an increased effort on the part of those three groups to prevent the accidents and diseases.

The increasing responsibilities now being placed upon designers and developers of products and services is a particularly significant one for the development of the discipline of safety science, and for institutions such as the THD in which so much new research and development goes on. Increasingly, and I believe it is a continuing trend, there will be legal as well as the old moral responsibilities to consider the future health and safety impact of designs, processes and products on the population that will work in them and with them or that will use them. It will then no longer be possible for an engineer or designer to say simply that their design is produced for purpose X in condition Y. Efforts will have to be made to predict, $\sum_{i=1}^{n} X_i$ in conditions $\sum_{i=1}^{n} Y_i$. The ranges of purposes and conditions must be defined in terms of the likely or conceivable behaviour of the customers, workers, or public, and must include predictable misuse as well as normal use. The need for prediction and modeling techniques which integrate human, technical and procedural elements is clear, if we are to respond rationally and scientifically to such pressures. Bolt-on safety is no longer acceptable. Guards and safety systems retrofitted to plant or personal protective equipment slapped on unwilling workers are expensive and largely ineffectual substitutes for proper integral safety systems. They are costly because the problems have to be solved hundreds of times over, by each user, instead of once by the original designer. They are ineffective because the cost-conscious factory skimps on their design and the maintenance necessary to make them work. Good designers should applaud these new legal developments because they allow them to do the whole of their job properly, and do not give the buyer the option of choosing something unsafe just because it is cheaper.

DIVIDING THE TASKS OF SAFETY

I have shown that the task of ensuring safety has become more complex and now explicitly involves more groups of people than ever before. I have pointed to the danger that this complexity can cause confusion about who should do what, and hence can lead to gaps in the actions taken. I want now to look more closely at how the total task of achieving safety is to be subdivided. As with any objective in research or management the achievement of safety can be seen in terms of problem solving, and I shall use the classic stages of problem definition and solution to provide the structure for my discussion.



In particular I want to indicate where gaps occur in solving health and safety problems at present and how safety science can assist in filling those gaps. To do that I shall take examples from the work of the Safety Science Group in Delft and of the department at the University of Aston from which I came.

VIBRATIONS AND SHOCKS

The subject of the chronic health effects of vibration of the whole body or of parts of it first raised its head with the introduction of mechanisation at the beginning of the century, and again with the great developments in power tools after the second world war. Attention came to be focussed on the effects of hand-arm vibration on circulation and nerve conduction, the so-called "whitefinger" syndrome found typically in users of pneumatic chipping hammers, road drills or chain-saws. (26) The ill-effects of whole-body vibration for drivers of transport vehicles and construction machinery remained at a much lower level of awareness until more recently (27), and were more usually thought of in terms of comfort than of their health effects on the back and internal organs. This was largely because the health effects are comparatively diffuse, develop progressively over a long period and produce symptoms which can also be caused by a wide range of other factors. In this sense they are typical of the health problems which safety science is now tackling; the cause effect link must be teased out from complex confounding factors, just as noise-induced deafness must be distinguished from age related hearing loss, and back injury caused by poor work posture and movement must be distinguished from muscle and joint ageing. It is characteristic of such diseases that they are dismissed to start with by managers of companies and manufacturers of equipment as "not their problem", "just a normal part of the ageing process" or "an overexaggerated complaint from a few sensitive people". Only where clearly defined groups of heavily exposed people show clear patterns of symptoms has the problem been seriously tackled. The result with vibration has been a piecemeal approach to what has been defined as a piecemeal problem.

For the past 3 years the Safety Science Group has been working on an inventory of the exposure to vibration in the Netherlands, to define the problem systematically. In doing so three groups in particular have been identified whose problems are not sufficiently recognised.

1. Users of vibrating tools such as road drills, where the solution has been defined in terms of a replacement technology (e.g. crane-mounted drills or road scarifiers) and whose problem is therefore regarded by technologists as solved. Yet there are still at least 10,000 workers in the country using those drills (with a heavy representation of immigrant labour), and many will go on using them because the alternative technology is too expensive for small undertakings. Insufficient problem definition and analysis has lead to too rapid closure of the problem solving loop for this remaining risk group.

2. Those in "neglected" industries such as agriculture, with scattered populations, many not subject to statutory reporting or inspection because they are self-employed, or such as construction with a very mobile workforce, where the problems do not become focussed enough to be noticed; there is no adequate monitoring and feedback loop. (28)

3. Those exposed to new uses of vibration and shock inducing technology, e.g. riveting pistols, hammer drills. These tools have come on to the market with insufficient protection incorporated and so will produce, in the coming years, their own epidemic of victims. This fact was entirely predictable, if available epidemiological knowledge had been linked to the technical knowledge of the designers of the tools. Again an information loop was missing.

I have said that problem analysis is hindered by the diffusity of the problem. This is reflected too in the lack of clear causal models of how whole-body vibration causes harm. Also little is known of how to assess the effects of the less frequent very high amplitude shocks, when a vehicle hits a bump at speed, or from the pneumatic pulse of a tool such as a pneumatic pruning shear. Because of this the standards available e.g. from the International Standards Organisation have some very arbitrary features. They are based upon laboratory research of the effects over short periods of simple, usually sinusoidal vibration on comfort and task performance. There is no standardisation of the posture of the subjects or of the environment in which the tests are carried out. These laboratory results are in practice then extrapolated to health effects of exposure to complex vibration, usually in combination with other stressors, over a working lifetime (29). The fit of the standards to reality is understandably poor. Standards are a necessary guide for designers and managers, but the danger is that their very existence gives the impression that the problem is solved, and again the proper solution process is short-circuited. For example, the existing whole-body vibration standard (ISO 2631) covers only vibrations between 1 and 80 Hz, whilst the inventory project discovered an important group of workers on vibrating compacting machinery in the pre-fabricated concrete industry subject to significant vibration well above 80 Hz which is not officially seen as a problem. Such shortcomings of standards are particularly important where the standards form the basis for the payment of compensation for work incapacity, or for defining where research or development money should be placed. The standard writers may insert all the caveats they like in the form of "the best estimate is...", "other factors should be taken into account, such as...", and so forth, but this is of little help to the designer or manager unless they have been taught the expertise to interpret those caveats, or can employ safety experts to do that interpretation for them.

The aspects of problem definition which I have covered are primary areas for the work of safety science, to tease out the real problem, and so to define the objectives for the development of low-vibration technology, of vibration isolation and of procedural ways of reducing exposure.

Excellent examples of technical solutions to specific vibration problems exist, for example for lorries. In other areas, such as chain saws appropriate knowledge exists of the theory of prevention, and its application has resulted in significant improvements, without as yet producing acceptably low levels of exposure. The technical gaps at this stage are in the refinement of the techniques available and their generalisation to the neglected areas, such as agricultural tractors, earth movers and pneumatic hammers. In such an technical task safety science plays only a supporting role to the technical disciplines. I believe however that it can still play a useful part; in developing data banks of successful applications of solutions to assist designers in the task of generalisation; and in feeding to researchers and designers information about the conditions of use of the technology, and about the mental models that the operators have of it, both of which can frustrate the use of otherwise technically excellent solutions. For example road drill users often reject vibration-isolated drills because they appear harder to steer, and they do not feel as though they are working as well or as hard. Safety science can also pick up the assumptions upon which the success of the technical solutions are based (e.g. good maintenance); assess whether they are reasonable ones given the likely conditions of use, and study how they might be incorporated into the procedural and training back-up to ensure an adequate and continuing total solution. That process leads to the final phase of the monitoring and evaluation of the effectiveness of the solution in terms of reduced ill effects. Here the same data collection and analytical techniques come into effect again as were used in defining the problem in the first place.

IN-DEPTH ANALYSIS OF ROAD ACCIDENTS

The example of vibrations and shocks gave an insight into the range of contributions of safety science. I now want to use some other examples of projects to emphasise specific aspects of the problem solving process. One common thread is the analysis of accidents to arrive at clear problem definitions. A particular case in point is a major cross-roads at Winsum in Friesland. Over the years this crossing has been the subject of several attempts to reduce the high toll of accidents. (In 1983 there were 13 reported collisions, in the first eight months of 1984 a further 7, leaving aside minor incidents which are known to have happened, but which were not reported). The attempts have included reconstruction of the carriageways and central refuges, through changes in road markings and signs and through planting of trees to provide a better visual background to increase visibility. None of the measures have resulted in a permanen reduction in the accidents, though some have had temporary effect. The dilemma is which measure to try next, given that all are costly. Is it worthwhile, for example, to abolish the crossing entirely by building a flyover, the most costly solution of all?

All the solutions tried are based upon different notions of the underlying causes of the crashes, and those notions come partly from accident analysis. We believe that this is the heart of the problem; that features of the accidents have been extracted at too low a level of abstraction from the incidents, and translated into immediate solutions, e.g. the observation that victims "did not see the cars on the second carriageway they had to cross" has been translated directly into attempts to improve that visibility. The analysis has not gone deeply enough into how that part of the driving task links with other aspects of it, and how changes in that part will be traded off with other factors in defining the ultimate behaviour of drivers towards the altered crossing. The analyses which the research team will do over the coming year will attempt to use a multi-disciplinary team of experts to add that extra level of abstraction. Critical data will be collected from the accidents which happen which will discriminate the different accident scenarios which happen in order to provide a basis for the rational choice of prevention measures. (30) This may involve fundamental research into the mental models that the drivers have of their task and how that is affected by the layout of the particular crossing. The implications of the research go far beyond this individual case. They should provide a better basis for the way in which data about the malfunction of any complex system can be collected and used as a feedback for design and redesign.

AS SAFE AS HOUSES? FALLS FROM STAIRS

The gross total of accidents in the home and leisure spheres far outweighs that in work and transport. The latest figures for the Netherlands are shown in the table.

SUMMARY ACCIDENT STATISTICS FOR THE NETHERLANDS 1981

	Deaths	Hospital Treatment	Total registered deaths & injuries
Industrial	62	3,071	75,515
Transport (incl. air & water)	1,876	25,868	53,505
Other spheres (leisure, home, etc.)	2,230	67,929	2,308,315

Estimate of occupational cancer deaths: 1,500 to 6,000 per annum

Total registered unfit for work under the law: 830,000 total in 1984

(Source: 31)

Table 1

Of those accidents in the private sphere some 7% or 160,000 accidents per year are falls from stairs. Precisely the same sort of question arises here as with the Winsum crossroads. For prevention purposes the Housing Ministry needs to know what measures are likely to have the most cost-effective impact on the accident problem. One part of the research is the development of ways of defining what are the predominant accident scenarios from the data currently available and such additional data as can be reasonably collected. Here we do not mean simple descriptions of accident and injury types, but much richer descriptions incorporating factors of the activity around the house, the characteristics of the stairs, and of the users and their behaviour. The second part of the research is to take the process further, to identify the aspects of those dominant scenarios which can be altered and to model the effect of specified changes on the accident rate. Then it will be possible to develop rationally based cost-benefit calculations with which to evaluate the priorities for prevention. The possible range of preventive measures to be considered is also greatly expanded by this method. It does not limit consideration just to modifications of the stairs themselves, but includes layout changes designed to alter patterns of use, e.g. provision and siting of laundry and toilet facilities, decisions to build flats rather than maisonettes (to eliminate all internal stairs) etc. (32)

One possible component of a solution to the problem of falls from stairs is to alter their dimensions (tread depth and size, steepness, presence of curves etc). A considerable amount of research has been done on such factors, and the result is a complex and detailed set of guidelines, often scattered among different official publications and research papers. These are tedious for the designer to interpret and incorporate into house designs and the danger is that they will therefore be ignored. The developments of Computer Aided Design offer possibilities here for allowing the designer to call up and use program modules which incorporate all of the norms and the trade-offs between them, (eventually linked to estimates of cost and effect on safety) and so to evaluate different design solutions.

SOLVING THE RIGHT PROBLEM

In all of my examples a common theme has been the need to carry out a deep enough analysis to be reasonably sure that the real problem is being addressed. The division of safety between the two camps of technologists and social scientists, which I mentioned at the beginning of my speech, has tended to work against this and to be reflected in one-sided definitions of the nature of many problems, and so of their solutions.

Protection of workers against noise & airborne contaminants is a good example. While equipment designers and installers have paid some attention to control at source, they have tended to consider that any exposure to harmful substances above the norms could be simply controlled by the use of protective equipment. The problem is therefore delegated to the user. Here too the assumption is made that wearing of the equipment is simple and only a matter of discipline and rule following, and that the real problem lies only in designing or buying equipment which is technically adequate, i.e.

which has the appropriate theoretical protection factor. The designer who believes that has only to observe on himself the effects of trying to carry out his own relatively light and sedentary task while wearing a full-face respirator for a whole day. Then he will appreciate that the problem of technical adequacy is only a small part of the whole safety problem. Such an exercise would indicate that criteria of wearability are as important to protection in practice, and that wearability and technical adequacy are often negatively correlated. When actual protection in practice is properly evaluated, together with the cost of training, supervision and maintenance of protective clothing schemes, what appeared a cheap solution looks very different. It can make financial as well as safety sense to throw the problem back to the original designer to incorporate control at source. (33)

Often the problem lies with the concept which technologists and legislators have of what can reasonably be expected of the users of their technology. The fault does not lie with the technologist, because nobody has seriously attempted to teach them, or to provide them with information about that behaviour in a form which they can use. That is a role for safety science.

THE ROLE OF SAFETY SCIENCE AND OF THE TECHNICAL DISCIPLINES

From my analysis it is clear that I place great emphasis on the role of the technologist in producing a major part of the solutions to safety problems. No new discipline can, nor should, try to usurp that role. The contribution of safety science lies in what added value we can give to improve on what is already done. The clue to that added value comes from the failures of the current system, the reasons why harm is not prevented. I have traced those to the inevitable limits which any discipline must draw around itself when it aims to study and master any subject in great depth. No technologist can be expected to be an expert in everything. There must be collaboration with others in the definition of what aspects of the problem can be solved by fundamental research in a technical discipline and of how those technical elements link with behavioural and procedural ones to produce a coherent total solution. It is therefore in the first four tasks in the solution process, and in the monitoring and evaluation task which links so closely to them that I see the major added value of safety science. It has, or is developing the range of systems based models and data collection and analysis techniques to provide the framework within which the technologist can locate his central contribution. Then it can predict and evaluate the effects of that contribution on the users of technology and on society as a whole.

I believe that the tasks of safety science can therefore be grouped under three headings:

1) The development of new techniques: to analyse system problems and the mental models that people have of those problems, and to predict and evaluate the effect of system changes, whether technical, procedural or behavioural.

2) The clarification and coordination of the contribution that each group within the system can make to the problem solving process. Here our role is one of a "process consultant", not usurping the responsibilities but helping the various groups to look critically at their own roles. I have pointed to the increasingly central responsibility that the researcher, designer & manufacturer are legally regarded to have for safety. The other central party in safety is the government, with its obligation to protect the well-being of the whole population. Clearly neither party can carry out single-handed all of the tasks involved, and must delegate many of them. But as ultimately responsible groups they have the duty to ensure that delegation is not equated with abdication of responsibility. If safety is to be achieved all 9 tasks which I have outlined must be done, and so responsibility must be accepted for all of them. Some guiding principles can be formulated for responsible delegation of the tasks:

- Adequate efforts should have been made to discover and to specify all dangers and all relevant responsibilities.

- The person/group to whom responsibility is given should be:
  - Informed of their responsibilities and how they interact with those of others;
  - Equipped with the authority to carry them out;
  - Provided with the knowledge, time and resources to carry them out.

- Their acceptance of the responsibility should be confirmed by them.

- An effective apparatus for monitoring and enforcing the execution of the responsibility should exist.

- Clashes between safety and other objectives should be made explicit and rules for solving those clashes should be provided.

Such principles can be used to test, for example, the actions of governments in a number of countries, which, under the banner of de-regulation, are withdrawing from specifying themselves the way in which industry should solve its safety problems. (34) It is a reasonable assumption that the appropriate expertise and resources exist in large organisations to accept these delegated responsibilities. But the case of small employers is quite otherwise. They have no such problem solving resources themselves. So they may be forced into buying them in at high cost from consultants in an attempt to fulfill their duties, or of doing nothing and so endangering their employees. A necessary corollary of delegation of detailed problem solving from government is a shift of emphasis in labour inspection towards stricter monitoring and enforcement if standards are not to slip.

3) The teaching of the techniques and responsibilities to the major groups concerned; teaching of engineers and scientists in the way in which their work interacts with the work of other disciplines to create and to solve safety problems (35); teaching to the safety experts who will head the Safety Services required under the Working Conditions Law, and who will man the government agencies and consultant bureaus to advise on and monitor the safety of people whether at work, in transport systems, in hospitals, or at home or play; and the provision of information to those who bear the risks, the workforce, and the general public.

These roles of safety science within the university structure fit well with those which the Minister sees, at the level of practice, for the safety specialist under the Working Conditions Law. In the explanatory memorandum accompanying the draft law he says:

"Its (the law's) design is based upon the concept that responsibility for safety conditions, just as in the existing law, rests on the shoulders of the highest management of an organisation, and upon those within the separate departments of that organisation who are entrusted with leadership: the so-called line-management. This means that the latter must possess a great measure of safety competence, above all in the technical respect, in the part of the organisation in which work is conducted under their leadership and responsibility. The role of the safety expert in this whole question is, on the contrary, according to this concept of the law one of an advisor to the management in the formulation of safety policy and of the methods by which it can be applied, and thereafter of an assistant in the carrying out of that policy. To do this the safety expert draws on the one hand on legal definitions, and on the other hand on general social norms." (36)

In these tasks the Safety Science Group does not stand alone in the university system. We form one of a cluster of overlapping subjects which concern themselves with these same problems of how to predict and avoid the unwanted effects of the interaction of man, technology and society. This group includes social & occupational medicine, environmental science, occupational hygiene, and ergonomics. The Technical University of Delft has a long, if somewhat chequered history of concern with these problems of health and safety. My predecessor, Prof Sleeswijk, had the dubious distinction in 1933 to be the only professor from this university whose post was abolished at a time of economies in higher education. I take it as a good omen that it is at precisely another time of such economies that the university has decided to begin my appointment and to reaffirm its committment to this subject.

I look forward with great anticipation to the work we have to do together. We are the human element that can solve the paradox with which I started, by incorporating both the human and the technical elements of the system in positive collaboration to produce a product that is greater than the sum of the two parts.

My most valued listeners,

At this the end of my speech I wish to give my thanks to Her Majesty Queen Beatrix for her decision to appoint me as professor in this Technical University. I thank also the University Senate, and the members of all the committees and boards for the trust they have placed in me. I consider it an honour that you have chosen me out of another country to come and teach and research in this world-renowned institution.

To the Advisory Council for Safety Science I extend my warmest thanks for the enormous amount of work they have done in establishing the case for the group within the University of Delft and for the discipline within the bounds of the university system. I shall look forward to the continuation of your advice, support and guidance in the many years ahead in which we shall work together.

To Prof. Jan de Kroes as my predecessor and chairman of the Advisory Council for Safety Science I give especial thanks. You have done more than anyone through your wise counsel and tireless enthusiasm to make the dreams of the seventies turn into the reality of the eighties, succeeding in times of general retrenchment in bringing to flower this new initiative. Without your selfless expenditure of time and energy, together with Prof. Asmussen, Prof Dirken and Prof Meuse I would not be able to stand here upon such well laid foundations to deliver this speech.

To my colleagues in the Safety Science Group I owe my deepest debt. You have made me feel at home since the day of my arrival, and have eased the troubles inevitable in a move from one country to another. Working with you is the best proof that anyone could wish for of the vibrancy and intellectual liveliness which I believe is inherent in work in multidisciplinary groups. To single out individuals is always invidious, but I know that you will none of you feel hard done by if I name only one. Louis; you were the first of the group to be formally appointed, five short years ago. Both before then and ever since you have built, guided, cajoled and lead it. You seem to have a dozen pairs of hands and at least three independent brains to run them. I think our colleagues in Information Science should use you as a case study for perfecting programmes for multi-tasking. Thank you for your help, guidance and friendship, without which my introduction to my task here would have been infinitely more difficult.

To my colleagues in the sub-department of Philosophy and Social Science I am also grateful for their welcome into their midst. I look forward to long cooperation with you in furthering our common task. My particular thanks must go to those colleagues who run the Dutch language course and who have made it possible for me at least to understand what I have said to you today.

Lest the tone of my speech should appear too inward-looking, let me also thank those people in industry, in ministries and in other research and education establishments who have shown confidence in this group by the research they have entrusted to us and by their strong support for our development. I look forward to the growing contacts I shall have with you in a common purpose of forging a strong discipline out of the various initiatives which exist in this country.

For 14 years before I came here I worked in this same discipline at the University of Aston, and through that work I came to teach and to work with colleagues from over 50 countries from the industrialised and the developing world. From you I have learned more than I can ever know. I hope that my work here will be a worthy continuation of what we started together. With such contacts and through the very nature of safety science and its abiding concern with system-wide interactions our subject must be the international science par excellence.

To my parents and family I also extend my greetings and thanks for traveling so far to be present on this day, which is I hope as proud for you as it is for me.

My fellow professors, lecturers and researchers, my speech has made clear how much I do and shall in the future depend on you. Safety Science works through others and with others. We add our contribution of impurity to your purer sciences to produce the alloy which in turn can solve the safety problems in the real world. I look forward to our collaboration to find the best formulation for that alloy and to explore its properties together.

Present and future students, as we in Safety Science do our work with and through the technical departments of this university, so do we all as teachers achieve our goals through you. This is an unsafe world and more and more people are looking to see who they can turn to, for help in making it safer, and for reassurance that it can be made better. People such as you can and must provide that help. It is our task and our pleasure to provide you with the techniques to do that duty, but above all to challenge and interest you in our subject and to make that duty fun to carry out.

My listeners, I have long detained you. I hope that my speech has shown you, as did my predecessor's 75 years ago, the many sides of safety science and of its contribution to the collaborative task we have: the task of all human factors in the system of limiting the damage we none of us intend but which we all do.

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