AUTOMATED VEHICLE GUIDANCE IN ROAD TRAFFIC: IMPLEMENTATION BY EVOLUTION OF VEHICLE TECHNOLOGY

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Abstract
Implementation aspects of Automated Guided Vehicles within the current road transportation system is subject of this paper. Many approaches to make traffic flow efficient and safe have been developed in recent years. Most of these concepts require new infrastructure, dedicated lanes and special equipped cars. In addition, these concepts concentrate on the application to freeways only, which are already relatively safe.

In contrast to these developments, a vision in which the whole traffic system could be adapted by a gradual implementation of modern technology will be investigated. Advantages and disadvantages of the different implementation approaches to substitute the conventional road vehicles by Automated Guided Vehicles are examined. The evolutionary approach seems the most promising implementation-trajectory towards the desired endpoint of a new, efficient and safer road transportation system. Research demands are formulated in order to assess the traffic flow quality impacts during the implementation trajectory and at the end-stage of the intelligent vehicle technology development.

1. Introduction

The current problems in the road transportation system in Europe, United States as well as in other countries, require sustainable solutions towards a more efficient, safer and a less space-demanding road infrastructure. One approach to this goal is the implementation of intelligence inside cars and at the road-side. This intelligence will have the knowledge of 'how to behave in traffic', or in other words: the in-vehicle and/or road-side intelligence has the capabilities to observe and interpret the traffic situation and cope like an expert driver would do. Therefore, we will define Automated Guided Vehicles (AGV) here as: vehicles, guided by a certain amount of intelligence affecting both driving tasks and traffic performance.

At this moment, there are already a number Automated Vehicle Guidance systems operational, for example at the ECT container terminal in Rotterdam and the VAL metro system in Lille. Other examples can be found in Hollier, 1987 and Cameron, 1994. However, these operational systems have a restricted area of application and can not easily be transferred to the situation of the extended public road transportation system with its many participants, diversity of objectives and possible conflicts. For public application in-depth investigations into the impacts, acceptance and possibilities of AGV implementation are desirable.
In this paper, a realistic view towards the implementation of Automated Guided Vehicles will be presented. First, in Section 2 the state of the art of AGV for road transport is set out. Also the expected advantages of AGV are described. The concepts will be discussed in Section 3, in which also a distinction between different implementation strategies will be made. Then in Section 4 expectations and assumptions about the technology development are drawn up and a resulting implementation-trajectory scenario is described. In Section 5 research needs are derived, which constitute in the framework of the TRAIL-Automated Guided Vehicles project at Delft University of Technology. In Section 6 a summary is given.

2. Automated Guided Vehicle Concepts

Various AGV concepts can be found in the literature. Let us first make a distinction between systems capable of taking over the driving task completely (autonomous systems), and systems taking over the driving task only partially, the so-called support or assisting systems. Information systems, either in-vehicle or road-side based, are not considered as essential AGV-concepts, although these systems can definitely influence the driving task (i.e. route-choice).

The assisting systems are developing rapidly at the moment. The automotive industry already implemented assisting systems having intelligence, such as ABS, fuel-injection, Automatic Stability Control (Nhagbeso, 1993) and Cruise Control (Pauwelussen, 1995). However, these systems do not affect the traffic flow quality in a negative or positive sense. In addition, these systems will bring more comfort and pleasure into car use by reducing some difficult or boring elements of the driving task.

The next generation of assisting systems, called the Advanced Vehicle Control Systems, certainly will affect the traffic flow quality due to the support of the interaction between following vehicles. Safety distances, deceleration rate and speed will be automatically regulated with the Intelligent Cruise Control (or less intelligent: Anti-Collision System) using sensors. Some preliminary studies indicate that a more stable, safer traffic flow without a capacity reduction will result when ICC is implemented (Beau, 1993), (Reiter, 1994). A further step towards the implementation of smart cars is the lateral control of a vehicle, using magnetic markers, radar, laser, acoustic or optical technologies (Chira-Chavala, 1993). Until now, the assisting systems are all in-vehicle based, but it may be expected that in the future also intelligence at the road-side will help the driver with his driving tasks. For instance, communication between vehicle and roadway to establish a reliable lateral control, including take-over manoeuvres, without the need of sensors. However, at this moment the AGV technology development concentrates especially on the in-vehicle devices.

In contrast to the assisting systems described above, the autonomous systems are partially centralized oriented: the intelligence is not only needed in the vehicles, but also at the road-side. A well-known concept is the Automated Highway System (Tao, 1995), constituted on the principle of platoon-driving, and theoretically able to reach a high capacity at high driving speeds (Stevens, 1995), (Rao, 1993). The entry/exit of the AHS, switching lanes, driving speed and deceleration rates are all controlled by the decentralized intelligence by making an optimal macroscopic assignment of vehicles to the infrastructure. Furthermore, an efficient communication of messages between vehicles is needed for microscopic fine tuning. For this concept, new infrastructure or dedicated lanes are a constraint to obtain the desired and expected positive safety and capacity gains of AGVs.
The AVG concept described by Lammen, 1993 is less intelligence-demanding. The use of sensors, and in a later stage the use of communication makes it possible to create an automated road transportation system with intelligence distributed over cars/roadside according to the implementation phase and available technology at that phase. We will already remark here that such a evolutionary based AGV implementation trajectory seems a logical continuation of the technology development (see also Section 4). Another AGV concept is the automatic autonomous system for correlative control of traffic, using in-vehicle intelligence and sensors to create a stable and efficient traffic flow on existing infrastructure (Pogorelov, 1995). In this concept, both the vehicle behind and the vehicle in front are determining speed, headway and deceleration-rates.

Of course, many other AGV concepts could be listed here, since the number of combinations of sensors, intelligence, actuators, communication (transmitters), the related traffic control algorithms, and the location of the devices at vehicle, driver or infrastructure is gigantic (Hall, 1995). However within the framework of this study the described differences between autonomous and assisting systems with a central or decentralized intelligence appears to be sufficient for further examination of implementation of AGV. See also Figure 2.1 where the three important components of the road transportation system are depicted.

It is generally assumed by many authors that automated highway systems carry the potential of a number of positive impacts (see eg. David, 1995). These possibilities refer to among other things:

- increasing the capacity of motorways (by decreasing reaction time and thus decreasing following headways)
- improving the traffic safety (by the presence of intelligence conflicts will be observed earlier and therefore prevented more often)
- improving driving comfort (the drivers’ task will be reduced by support systems)
- reducing environmental impacts of motor vehicle traffic (by speed and deceleration regulation)

These advantages are desirable, however their future realization can be argued. It has yet to be proven that road capacity will increase, when looking at a complete road network. Moreover, only a capacity gain at freeways can eventually result in just a little improvement for the travelers, since secondary roads and parking facilities probably can not increase their capacity level, or not as fast as it occurs on freeways.
It can also be argued if traffic safety can be enhanced by intelligence. Are the sensors and intelligence capable to observe and interpret the traffic situation as good as as fast as human beings? Also in special occasions? Furthermore, the possibility of improved driving comfort can be doubted since many drivers like their driving tasks and do not want to miss it. However, since the possibilities are promising, further investigations should be performed in order to assess the actual gains in road capacity, road safety, comfort-level and environmental impacts.

3. Implementation Strategies

Concerning implementation strategies, we can distinguish three different approaches when we focus on the physical appearance of Automated Guided Vehicles on the public road infrastructure only. They will be described below.

In the first method, sometimes denoted with the revolutionary approach, the Automated Guided Vehicles can only be used on dedicated lanes, and not in a mixed situation with the presence of conventional vehicles. As long as the penetration rate of the AGV is very low, an efficient use of the dedicated AGV-lanes is not possible. Moreover, when the penetration rate increases, an expansion of the necessary AGV infrastructure will be needed. Since costs and acceptance of the system are important factors for large scale implementation, it seems that realization of this 'single-mode and single-advantage' scenario towards an automated transportation system will be hard to achieve.

![Diagram](image)

Figure 3.1 Three implementation scenarios towards an automated road transportation system

A second strategy can be seen as a further extension of technology incorporated in the Automated Guided Vehicles. Not only can the smart cars drive on the dedicated lanes or roads with the expected advantages in safety, capacity and comfort-level, but they can drive in a mixed situation...
with conventional cars as well. In addition, the appearance of smart cars in mixed traffic can possibly affect the traffic flow characteristics, since they can be equipped with technology able to support (or in a later stage: completely take over) the drivers' driving task, although this is no requirement for a dual-mode traffic system. The AHS concept is based on this implementation strategy, which is a more realistic approach than the singular-mode implementation strategy described above, although the dedicated lanes are necessary to enhance road capacity and safety. This implies an increasing investment in new and adapted road infrastructure as the AGV penetration degree increases. Therefore, due to the expected costs, it is doubtful whether such a concept eventually will replace the existing transportation system. Eventually, such a 'dual-mode and singular-advantage' strategy will result in a 'singular-mode' system when all conventional cars are replaced, and the therefore needed infrastructure adaptations are made.

The third strategy is based on a variant of the latter strategy. It is assumed that Automated Guided Vehicles can drive on all roads, even in traffic situations where no advanced cars are involved. The AGVs are specially designed and developed for this 'dual-mode and dual-advantage' task, and will bring advantages in traffic safety and efficiency in both mixed traffic and non-mixed (thus at dedicated lanes or roads) traffic flow. Dedicated lanes or roads can specially be arranged for the AGVs, but the vehicles will function as if they were in mixed traffic circumstances. This is the expected evolutionary trajectory towards the endpoint of the advanced vehicle implementation in which only AGVs will be present in (freeway) traffic.

In the following sections, we will further focus on this third strategy, since the expected evolutionary approach of this strategy seems the most promising one compared with the other more revolutionary approaches. The unrestricted use of existing road infrastructure with the presence of both conventional and advanced vehicles constitutes the decisive factor to this preference.

4. Technology development and the Expected Implementation-Trajectory

The current state of technology seems to be sufficient to implement in-vehicle intelligence applications on a large scale, although the existing Advanced Vehicle Control System can only support the driver in certain tasks or restricted circumstances. The Cruise Control is already an accepted in-vehicle driver-support system, and with the application of lasers (or optical technology) to determine a safe driving distance, the drivers' support system can be enhanced with an Anti-Collision system. In addition, this type of support system can be denoted with (Autonomous) Intelligent Cruise Control, when driving speed and deceleration are controlled by the vehicle.

Besides the driver support in longitudinal direction, with the utilization of the various sensors available today, support systems can (and are) developed to support the driver in lateral manoeuvres. Of course, the operational aspects of these systems can vary between warning signals to automatic steering. Acceptance, comprehensibility, costs and reliability are the keywords for large scale implementation of a certain support system, and its operational aspects.

Looking back in history, we can estimate and visualize the substitution process of the road vehicle as an s-curve with a time period of about fifty years, before the saturation rate of 90% was reached (Griehl, 1989). Therefore, we can develop a implementation scenario of Automated Guided Vehicles based on the same substitution process, which can be described by a logistic function. The total duration is just an estimation, but let us assume a period of another fifty years before a saturation rate of 90% will be reached. See Figure 4.1 in which two elements of the process are visualized: the substitution process of the vehicle fleet (estimated replacement rate of vehicle park 15 years) resulting in four generations of advanced vehicles, and the increasing
intelligence incorporated in each new generation vehicles (the increasing intelligence-rate is shown by the major s-curve)

We can distinguish five expected sequential stages in the development of Automated Guided Vehicles, although the actual division into stages will not be as strict as described here:

1. First stage is already started. The development of advanced cars is just beginning (ABS, Cruise Control). In general, these conventional 'intelligent' vehicles do not substantially affect traffic quality and safety.

2. The next generation of vehicles will replace these cars and will be equipped with more intelligence: the already mentioned Anti-Collision systems or Intelligent Cruise Control, using sensor technology (radar, laser, video). The lateral control technology will develop during this second stage, and will be fully operational in the third stage.

3. However, automated steering will be restricted since the sensor technology is assumed to be not error free. In addition, the in-vehicle technology will focus on communication between the traffic participants and the road-side.

4. The sensor technology will be substituted by communication, satellite (Global Positioning System) and data technology during the fourth stage (Lasky, 1999). Herewith, a more reliable longitudinal and lateral support can be created. However, sensors stay necessary as long as a mixed traffic situation exist and is allowed.

5. In stage five, a further substitution of older cars with intelligent, communication-based, vehicles will take place (not depicted in Figure 4.1). Certain road types can be dedicated for sensorless AGVs only. In addition, with a penetration rate of 100% AGV, it will be possible to create new applications and belonging advantages, using communication between the decentralized (road-side) intelligence and the vehicles. Individual path assignment (dynamic reservation of lanes) will make a more efficient utilization of the road infrastructure possible.

This evolutionary implementation trajectory is just based on expectations and assumptions, with great uncertainties. However, since the technical specifications of the traffic control systems and in-vehicle support systems are not yet specified and therefore easily adaptable (e.g. safety distances, warning distances, lateral control algorithms and lane assignment strategies) within the here described view of the development of Automated Guided Vehicles, a well-chosen and flexible startpoint for further research into the impacts concerning traffic quality, safety and geometry is created.
5. Research Demands

The implementation of Automated Vehicle Guidance within the public road transportation system will not only have its impact on the traffic flow quality, but also on many other areas. Within the TRAIL 1 Automated Guided Vehicles project, four areas of interest are covered. One of the long term research projects focuses on the individual driver and travel behaviour, a second one concerns the societal consequences and policy making (see eg. Van der Heyden & Marchau, 1995), and an other focuses on the juridical aspects and consequences due to the implementation of Automated Guided Vehicles within the public road transportation system.

In this paper, the impact of AGV on traffic flow, safety and road infrastructure design, also a long term project, is the main topic.

Most of the studies into achievable capacities with AVCS equipped vehicles (i.e. Intelligent Cruise Control, Anti-Collision System) look at the performance of just one road section. For this task, simulation models are used since field tests can not be carried out with non-existing advanced vehicles, or with the required penetration rate.

However, for a realistic and therefore valuable evaluation of the AGV implementation impacts, the simulations should be applied at a larger scale area, including exit/entry processes. Instead of just a link with a restricted number of intersections, a whole road network should be considered for evaluation. Of course, without knowing the impacts on microscopic scale, this task can not be accomplished. Therefore, the following research questions emerge, eventually resulting in a comprehensive network analysis. The development of a purpose-specific (microscopic) simulation model will be a requirement for most of the research demands, so this is an research demand too.

- Investigate the capacity and traffic flow characteristics for one-lane roads (eventually for macroscopic modelling on/off ramps) over the complete implementation period and thus different penetration rates for the various intelligent vehicle types present;

- Investigate the capacity and traffic flow characteristics for motorways with different infrastructure configurations, including a variation in the number of lanes and different kinds of intersections, over the complete implementation period while taking into account the expected vehicle fleet composition at different stages;

- Investigate the capacity and traffic flow characteristics for unsignalized two-lane, two-direction highways over the expected implementation trajectory;

- Develop the required, or desirable, traffic control systems for the different stages. The design of the transition sections is a related issue and needs study;

Besides the capacity impacts, the road safety consequences have to be assessed. For this goal a clear definition for road safety has to be defined. Since the safety (but also road capacity) with advanced vehicles depends on the characteristics of the intelligence, communication and sensors, further research demands emerge:

- Determine the existing or expected characteristics of the in-vehicle and road-side elements affecting the traffic safety and traffic flow quality;

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1 TRAIL = Research School on Transport, Infrastructure and Logistics
• Adapt an existing microscopic model with new driver behaviour (using the advanced vehicle in an intelligent environment)

• Define and model road safety, based on error expectations of the in-vehicle and road-side elements (actuators, intelligence, transmitters, sensors)

Having achieved these tasks, an existing road network has to be chosen for further examination into the achievable capacity and safety gains. A (macroscopic) simulation model may be used for this task. Thus:

• Develop a model for analysis of a road network on a macroscopic scale and examine the traffic flow impacts of the implementation of Automated Guided Vehicles, using different scenarios. The results of this case-study are needed to assess the impacts on the traffic flow and will contribute to an overall assessment of the societal desirability of AGV.

Also scenarios for modelling the spatial and societal developments over the implementation trajectory need to be defined.

6. Conclusions

In this paper we presented some considerations with respect to the expected future introduction of Automated Guided Vehicles. The often mentioned possibilities to increase road capacity, road safety, driver comfort-level and environmental quality led to a recommendations for a study aiming to assess the actual possible improvements of the road transportation system.

The framework of the study will be an evolutionary implementation approach which seems to be the most logical, acceptable and practical strategy. The more revolutionary approaches, such as the American AHS concept, require valuable infrastructure adaptations for implementation and therefore seem not appropriate to envisage first.

The evolutionary implementation trajectory can be divided into five stages, covering a period of about fifty years. In the first stage, no substantial impacts from already applied Advanced Vehicle Control Systems are apparent. In the second stage, with the more intelligent sensor-based AVCS facilities implemented on a large scale, the traffic flow will be affected. Besides the longitudinal control with sensors, the third stage also comprises the implementation of lateral control in the vehicles. During the fourth phase, which is a transition phase, the technology concentrates on communication instead of sensors. With this a more reliable longitudinal and lateral control can be achieved. However, a centralized road-side intelligence is then required for coordination. The last phase is especially communication-based. The sensor-equipped vehicles are no longer allowed on certain road-types. New applications, such as dynamic decentralized macroscopic lane assignment, are possible on the AGV permitted road-types, and will affect the traffic flow quality positively.

With the use of a purpose-specific microscopic simulation model, the future traffic behaviour with intelligent vehicles in its various development stages can be studied. A network analysis with a macroscopic traffic model is needed to assess the overall desirability of AGV implementation.
References


