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**Technology Assessment of
Automated Vehicle Guidance**
Prospects for automated driving implementation

Ir. V.A.W.J. Marchau

Delft University Press, 2000

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**Technology Assessment of
Automated Vehicle Guidance**
Prospects for automated driving implementation

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Vincent Albert Willem Julia MARCHAU

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To: Nathalie and Nicolas



Preface and Acknowledgements

Large efforts are made to improve the intelligence of road transport systems by developing and implementing a variety of telematics systems. Today, a variety of measures is proposed and gradually implemented to improve the use of road infrastructure. Emphasis is laid on traffic management measures such as: traffic guidance systems, early warning systems combined with route information, speed regulation, flexible lane use, etc. The driving forces behind this development are the need for a more efficient use of the existing road infrastructure, reduction of congestion and the improvement of traffic safety and comfort of travelling.

In this thesis the technically most advanced systems in this context, labelled as Automated Vehicle Guidance (AVG), are studied. These systems are characterised by the use of technologies partially or even totally automating the vehicle driving task. AVG has a high potential regarding the improvement of transport and traffic impacts, as compared to other telematics systems, as these systems put the driver out of the driving loop. Until now, however, it appears that the potential of AVG has only been proven in theory under ideal conditions. As such, there is much uncertainty on future AVG developments and implementation in real traffic.

This thesis focuses on the prospects for the implementation of these systems on a large scale. The results should provide knowledge on the societal consequences of the implementation of AVG technology to the public authorities involved, in order to support the development of their policy strategy and to identify important issues for follow-up, in-depth research.

The research presented within this thesis has been conducted at the Transport Policy and Logistical Organisation Section within the Faculty of Technology, Policy and Management of the Delft University of Technology (DUT). It was part of a multidisciplinary research programme 'Technology Assessment Automated Vehicle Guidance', initiated by the Dutch Research School on TRANsport, Infrastructure and Logistics (TRAIL). This research programme was funded by the DUT Beek Commission and included four PhD projects in which the implementation issues of AVG were studied at different levels. Marieka Hoedemaeker researched the drivers' acceptance for AVG and the effects of AVG on individual driving behaviour. Michiel Minderhoud studied the impacts of AVG on road capacity and traffic flows. Kiliaan van Wees investigated the legal aspects of implementing AVG in road traffic. I thank them all for the discussion and cooperation I have experienced in performing our joint research programme.

I also wish to express my gratitude to all my colleagues at the Transport Policy and Logistical Organisation Section. In particular, I thank my PhD thesis supervisor, Rob van der Heijden, for his intensive support regarding the content and progress of my research activities over the past five years. His willingness and capability to reflect critically on my work and to generate innovative research avenues has been very stimulating to me. Furthermore, I express my thanks to my colleagues John Baggen, who introduced me in the

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Writing a PhD thesis absolutely needs moral support from the people at home. I would like to express my gratitude to my parents for their intensive, stimulating interest in my research progress and accomplishments. Their relativism and common sense helped me during the completion of my dissertation. Finally, there are the two most valuable people in my life, Nathalie and Nicolas. I would like to express my deepest thanks to them for their unconditional support and never-ending trust in me over all these years. They were always there to listen to me, stimulate me and advise me during good and bad times. I owe them a lot!

Vincent Marchau
Delft, December 1999

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Chapter 1.

Background, scope and objectives of this thesis

1.1 Introduction

In this chapter, the background, context and objectives of research within this thesis are given. This thesis deals with the implementation of Automated Vehicle Guidance (AVG) within the context of public policy making. The reason for addressing this theme lies in the growing expectations about the potentials of AVG to reduce traffic problems. In section 1.2, therefore, the potential of AVG implementation for the contribution to general transport policy goals is considered. Next, in section 1.3, today's public policy involvement in the US, Europe and Japan regarding AVG is explored. In section 1.4, it is argued that today's policy making is insufficient to successfully implement AVG. In section 1.5 this insufficiency is related to a lack of scientific research in this field. This deficiency yields important questions, which will be dealt with in this thesis.

1.2 Background

Modern societies are increasingly confronted with the externalities of road traffic, i.e. congestion, unsafety, consumption of scarce space, use of energy and emissions. Several measures are currently considered by public authorities in order to control these externalities. These measures vary from incentives (e.g. charging vehicle use), regulations (e.g. restricted lane use to specific groups, speed limitations under certain traffic conditions) to the implementation of new transport telematics technologies to make the (road) transport system more 'intelligent'. In general transport telematics refers to combining information and communication technology, as a result of which (road) traffic data is collected, processed and transmitted to transport users and/or operators.

The importance of these transport telematics systems for the organisation and management of dynamic transport processes increases rapidly (Banister, 1994; Hall 1995). This can be explained by the increasing technical possibilities to improve the intelligence of cars and infrastructure for the support of driving behaviour and a better management of traffic flows. Further, it is generally expected that telematics will contribute significantly to public policies aimed at organising passenger and freight transport more efficiently, safer and more environmentally friendly (Harvey, 1995; Shladover, 1995; Levine & Underwood, 1996). Consequently, macro economic developments will, according to this view, also gain benefits from the application of transport telematics; less congestion yields a better accessibility to economic areas.

Within the broad field of transport telematics, different categories of application can be distinguished, each being focused on a specific transportation problem area. For instance, in the United States transport telematics has been subdivided into the following categories (e.g. Catling, 1994; Mast, 1998):

- advanced traffic management systems, concerned with a more efficient organisation of traffic flows through the infrastructure network;
- advanced traveller information systems, providing travellers with information on optimal mode and route choice before and during a trip;
- advanced vehicle control systems, improving vehicle driving performance by automation of vehicle driving tasks;
- commercial vehicle operations, assisting commercial fleet-operators in managing their fleet more efficiently;
- advanced public transportation systems, focusing on improved effectiveness and efficiency of public transport;
- advanced rural transportation systems, serving particular needs of efficient driving in rural areas.

In Europe a similar subdivision of transport telematics has been used, with one significant addition: the area of demand management (Whelan, 1995). Demand management deals

with technologies to influence transport demand in such a way that: 1) the growth in demand for scarce road capacity is limited, and 2) the demand is better spread over the day (less peaks). A well-known example of this approach is road pricing.

The category of advanced vehicle control systems probably has the highest potential in contributing to better use of existing road infrastructure, as compared to the other categories of transport telematics, since these systems intend to put the driver out of the traffic loop (Klijnhout, 1995; Coëmet, 1997). In the Netherlands these systems are also known as Automated Vehicle Guidance (AVG). These devices inform or automatically support the driver in critical driving conditions, in order to improve the vehicle driving task. Potentially, AVG offers important advantages for road transportation: more control on speed and position of vehicles on the road is important for establishing more homogeneous traffic streams and to reduce the number of accidents. As such AVG is assumed to have a positive impact on the use of road infrastructure and traffic safety (e.g. Boussuge & Valade, 1994). Moreover, this could lead to a reduction of energy use and emission of environmentally harmful gasses. Finally, part of or even all vehicle driving tasks are supported and/or executed automatically by AVG. Hence, vehicle driving could become more comfortable and more convenient as compared to today's manual driving.

A variety of AVG systems are currently researched and developed. Some systems are already marketed on a limited scale. For instance in Japan, collision warning systems have been marketed independently for trucks by Mitsubishi, Nissan and Hino since the early nineties. These systems measure the distance to preceding vehicles and warn in case of following too close. In the United States, a collision warning system has been manufactured and marketed for trucks and buses for three years now by Eaton VORAD technologies (Woll, 1997). This system warns a driver in case of driving too close to preceding vehicles or in case of blind-spot obstacles present during lane changes. A general application of collision avoidance systems could reduce accidents up to 40 percent (Broughton, 1994). In Europe, more attention has been given to intelligent or adaptive cruise controls, i.e. cruise controls which adapt a vehicle's speed and distance to the preceding vehicle. This system initially supports the driving comfort but, under specific conditions, also road capacity improvements may be achieved. According to simulation experiments, adaptive cruise control could increase road capacity up to 25 percent (Morello et al, 1994). In Japan, a first speed headway support system is put on the market by Mitsubishi. This so called 'Preview Distance Control' is a laser-based system which measures the distance to the nearest vehicle ahead and, if coming too close, decelerates by using throttle control (Blancett et al, 1997). In addition, systems are currently under development which support the total longitudinal driving task, based on integration of existing technologies (Sala et al, 1997).

The exchange of information or cooperation between a vehicle and other vehicles and/or infrastructure is expected to further improve traffic safety by giving, for instance, preview information on forthcoming obstacles and optimising traffic throughput by automatic speed adaptation to local traffic conditions. Cooperative intelligent cruise control, for instance, communicates information of the vehicle dynamics to a following vehicle. Hereby, two or more equipped vehicles can cooperatively 'platoon' on the motorway using basic sensing

plus inter-vehicle communication and computer processing (Wilson, 1994). These systems may also include the possibility to receive information from the infrastructure about the roadway such as the local speed limit.

It is generally expected that one of the results of this development will be fully automated facilities where the driver's steering, throttling and braking tasks are totally taken over, allowing feet-off and hand-off driving. This 'autopilot' in combination with dedicated lanes could allow equipped vehicles to group themselves in platoons, which harmonises traffic flows and optimises throughput significantly. Preliminary studies indicate that on fully automated driven lanes, compared to manual-driven lanes, an increase of 80 to 90 percent in safety (less accidents) and a capacity increase of 200 to 300 percent could be feasible (Kanaris et al, 1997; Bishop & Stevens, 1994). Together with substantial reductions in travel time (percentages up to 50 have been mentioned), fuel consumption and emissions, this implies high potential advantages in the long run.

Even though available technologies will not be sufficiently reliable to fully replace the driver by automatic systems in the near future, they do offer a wide range of new possibilities for driver support in the short term (Naab & Hopstock, 1995). Consequently, as the technology seems feasible, nowadays the focus in R&D and societal debate is shifting from technology development to the implementation issues of these systems in real-world traffic. This has been taken as the central theme of the research programme 'Technology Assessment on Automated Vehicle Guidance', which started early 1995 within the Dutch Research School on TRAnsport, Infastructure and Logistics (TRAIL) at Delft University of Technology (Van der Heijden & Wiethoff, 1999). At present, this programme consists of four PhD projects in which the implementation issues of AVG are studied at the levels of respectively driver and travel behaviour (Hoedemaeker, 1999), traffic performance and infrastructure design (Minderhoud, 1999), legislation and tort liability (e.g. Van Wees, 1998), and societal consequences and public policy making. This thesis takes the latter issue as its subject.

1.3 Public policy making on AVG

Over the years the policy involvement in AVG has been limited to three geographical areas: the United States, Japan and Europe.

The United States

During the eighties the need for national public policy making with regard to transport telematics in the United States increased, after years of initiatives at local and regional levels. In August 1990, a non-profit organisation was founded, currently known as the Intelligent Transportation Society America (ITS America). ITS America has an 'umbrella' function to all domestic public and private organisations involved in transport telematics, aiming at organising and coordinating research and development. In 1991 research on transport telematics was further institutionalised by the Intermodal Surface Transportation Efficiency Act (ISTEA), approved by the US Congress. This act comprehended a national

ITS programme for six years, financing for research and development of ITS technologies within the USA. Part of the ISTEA concerned the active development and demonstration of an Automated Highway System (AHS) by the US Department of Transportation (USDOT). This department established an AHS programme based on a public-private cooperation of national AHS stakeholders. The AHS activities concerned the analysis, definition, and operational test and evaluation of various AHS options and issues (Saxton, 1994). In 1997 some intermediate results of this programme were demonstrated in San Diego. Here, different automation concepts were shown to public at large. During this period the DOT indicated the need for more attention to applications of vehicle automation for the near future. It appeared that the research consortium on AHS could not fulfil this need and hence, in 1997, the DOT replaced the AHS programme by the Intelligent Vehicle Initiative (TRB, 1998). This programme focuses more on near-term applications of vehicle driving automation. The IVI programme features cooperation between industry, states, and other organisations. It includes the development of intelligent vehicle concepts, early field-test evaluations with an emphasis on assessing benefits and user acceptance, and associated pilots and demonstrations.

Japan

In Japan the implementation of transport telematics began early. The explosive growth of the Japanese road traffic in the seventies in combination with scarce space for new roadways induced a need for innovative transport management. Since then, Japanese public authorities have structurally been investing in development and implementation of traffic management technologies and travel information systems (French et al, 1994). Today's Japanese infrastructure is consequently provided with several systems in order to manage and control the traffic. Throughout the years different Japanese ministries have established research programmes on transport telematics. In 1994 the need for coordinating the various initiatives led to the foundation of the Vehicle, Road and Traffic Intelligence Society (VERTIS). VERTIS is the equivalent of ITS America. It aims at coordinating developments among public and private parties involved in transport telematics.

Some of these research programmes cope with automated driving. In 1989 the Ministry of Construction started the Advanced Road Transportation System (ARTS) programme. This programme initiated research on intelligent coordination between vehicles and infrastructure, focusing on the development of road facilities for roadway monitoring, collision avoidance and road pricing. At the same time the Ministry of International Trade and Industry conducted the Super Smart Vehicle System (SSVS) programme, initiating research on several driving control devices including driver, vehicle and roadway monitoring, automatic collision notification and longitudinal and lateral control. In addition, the Ministry of Transportation started the Advanced Safety Vehicle (ASV) programme in the early nineties. This programme focuses on developing collision avoidance systems. In addition, in Japan, a serious effort has been made with regard to research and development of Automated Highway Systems (AHS). In Japan AHS is known as Advanced Cruise-Assist Highway Systems. In 1996 the main Japanese

corporations joined up to establish the Advanced Cruise-Assist Highway System Research Association (AHSRA), in order to develop the necessary technologies for automated driving.

In summary, Japan is leading regarding the implementation of transport telematics applications as compared to the US. However, the consensus and coordination at national level regarding the implementation of ITS is less well-developed (Shibata & French, 1998).

Europe

In Europe the research and development on transport telematics has been going on for some years. Two major programmes are relevant in this context: PROMETHEUS (Programme for European Traffic with Highest Efficiency and Unprecedented Safety) and DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe). PROMETHEUS was an eight-year research programme in which 17 European car manufacturers and electronic industries participated, partially funded by the European Community. Daimler-Benz initiated PROMETHEUS in 1986 and aimed at a pre-competitive cooperation between European automotive manufacturers regarding the development of intelligent vehicle systems for traffic safety, drivers comfort and road efficiency. The results of PROMETHEUS were demonstrated by Common European Demonstrations (CED). The CED study the technical feasibility and impacts on traffic of several near-term vehicle control applications. These were not regarded as prototypes, but more as alternative avenues to the future. Several near-term applications for automated driving have been researched within PROMETHEUS. In addition, the DRIVE programme, funded by the European Community, started in 1988. It was followed by DRIVE II and DRIVE III and is ongoing. DRIVE was initially more oriented towards intelligent infrastructure, i.e. the research and development of systems in the field of traffic management and travel information, although some applications for driver monitoring and warning have also been considered in the early programmes (Hayward et al, 1997). Later, the scope within follow-up research programmes on transport telematics within the European Community has been broadened towards, a.o. vehicle control and driver assistance (e.g. Maltby & Morello, 1997).

In 1991 the European Road Transport Telematics Implementation Coordination Organisation was formed (ERTICO). ERTICO is the equivalent of ITS America and VERTIS in Japan. It is a public-private effort to coordinate ongoing transport telematics research in Europe and to support implementation (Whelan, 1995).

Furthermore, some national initiatives have recently been taken within Europe. For instance, in the Netherlands increasing policy efforts are made to improve the transport system performances by developing and implementing a variety of transport telematics systems. These policies are part of the ambitious *Second Transport Structure Plan* (Ministry of Transport, Water Management and Public Works, 1990) to tackle the serious congestion problems, to improve traffic safety, to reduce environmental impacts of traffic and to increase the economic importance of transport facilities. In this decade most attention has been paid to electronic systems in the field of traffic management and travel information.

Research indicates that traffic management and traveller information measures (such as ramp metering, reversible lanes, traffic signal systems, dynamic route information systems, and incident management systems) lead to a better and safer use of the existing infrastructure. Within the context of dynamic traffic management, much attention is paid to the possibilities of better informing car drivers. It has been found that information by radio and dynamic route information systems enables the driver to better plan his/her travelling through the network and reduce the risks of unaccepted travel time losses. Systems for better informing car drivers in the network are generally seen as typical of the first phase of a development towards AVG (Catling, 1994). Therefore, the implementation of these systems is strongly encouraged and facilitated by the Dutch government.

In the Netherlands, in 1996, an ITS society was established as a platform between governments, research institutes and automotive and telematics industries. This public-private organisation was founded in order to improve the implementation speed and quality of ITS solutions for transport and traffic problems (Ministry of Transport, Water Management and Public Works, 1998). So far, the practical importance of ITS has been limited, although the attempt to bring relevant parties together to stimulate the interactions and debate, seems very fruitful. Moreover, very recently, a special ITS subcommittee for AVG has been established. Furthermore, in 1994 public funds were submitted for improving the knowledge infrastructure in the field of transportation. Part of these funds was used to further elaborate concepts for automated freight transport (e.g. the so-called Combi Road concept for automated freight transport), building upon the Dutch experience with the use of automated guided vehicles at the modern European Combined Terminal for container handling in the port of Rotterdam. Later, since the mid nineties, automation of freight transport was combined with thoughts about underground logistic systems, resulting in a promising initiative for an underground automated logistic system at Schiphol (OLS). The attention for AVG in motor traffic has developed much slower in the Netherlands as compared to freight traffic. In 1998 the Ministry of Transport, Water Management and Public Works published a so-called business plan in cooperation with a number of research institutes (Coëmet et al, 1998). This plan considers some initial steps to come to a view regarding the implementation of AVG, which supports public decision making. In addition, in 1998 the Ministry organised a big international demonstration of AVG in Zoeterwoude and recently, a pilot has started for testing intelligent speed adaptation systems in Tilburg.

Summarising, a considerable amount of research has been undertaken on AVG within the US, Japan and Europe. Public authorities have been facilitating this research and development intensively, playing the role of R&D manager. Furthermore, organisations have been founded to coordinate research activities on (inter-) national level for transport telematics in general. Regarding AVG, most research and development has been focused on technological development and improvement. The technological feasibility of most AVG systems and their potential in reducing negative traffic impacts has been demonstrated within several controlled experiments and pilots. Consequently, the focus in this field is now gradually changing from technology development towards the possibility of

technology implementation in real world transportation. This raises new issues about public policy making, which will be elaborated in the next section.

1.4 Research issues for public policy making

A major problem for public policy development concerning AVG is the existence of much uncertainty on future AVG development and implementation. There are different issues which induces this uncertainty, i.e. so-called sources of uncertainty, including (Van der Heijden & Marchau, 1995):

- the relationship between AVG and general transport policy goals;
- the most likely development of AVG technology implementation;
- important societal conditions for implementing any form of AVG technology.

AVG and general transport policy goals

Although there exists optimism about the contribution of AVG systems to transport goals, the fact is that there still is a great deal of uncertainty about the real impacts, which makes public authorities hesitate about what should be done. For instance, AVG systems which support drivers in keeping sufficient distance between vehicles because of safety considerations, i.e. autonomous intelligent cruise controls, might cause the situation that the average number of vehicles per distance unity is considerably lower as compared to the situation of absence of those AVG systems. This contrasts with the aim of intensifying the use of infrastructure capacity and might even imply the need for a considerable extension of infrastructure capacity.

Another possible conflict might occur with goals in the field of traffic safety (Marchau, 1998). Indeed AVG systems are able to reduce the collision probability for vehicles on the road. As such, they contribute to the reduction of the number and severity of accidents. However, in the longer run AVG might induce adaptive driving behaviour patterns by car drivers, causing higher risks for other groups in traffic, such as pedestrians and cyclists. AVG might also contribute to more aggressive behaviour of car drivers being confronted with clear limitations of their freedom (e.g. speed, passing by). In particular, when the automates are not intelligent enough to handle different types of infrastructure- and traffic situations, drivers could react aggressively with respect to individual control, compensating the experienced limitations on AVG controlled driver tasks. The conclusion is that a lot of questions still remain to be answered with respect to the relationship between AVG and traffic safety.

The likely development of AVG technology implementation

The previous issue dealt with uncertainty about the impacts of AVG implementation. Evidently, there is a strong relationship between these impacts and the nature of implementation. Basically, each implementation strategy has to cope with at least the following questions regarding the first phases, to be expected within the next two decades:

- will a vehicle-centred or an infrastructure-centred AVG technology be chosen, i.e. will the intelligence be incorporated in the car, or is there an explicit need for including intelligence (sensors, communication facilities) in the infrastructure as well?
- will the implementation be radical (replacing one transport system by another) or evolutionary (simultaneous use of traditional and new transport system and gradual change of the mix)?
- will the implementation focus on the motorway system first and then on the underlying network or will the focus be on the integral introduction of a particular system/technology on the entire road transport network in the regions?
- will the implementation be accessible for all car drivers or will the focus be on particular groups of drivers (e.g. elderly people or business representatives)?

Clearly more of these questions can be put forward which refer to the way of implementing AVG technology on a large scale (e.g. Al-Ayat & Hall, 1994). At this moment a primarily car-centred and thus business pushed implementation, has been started at a limited scale. As indicated in section 1.2, the first AVG systems are typically marketed by vehicle manufacturers as comfort and/or safety features for individual vehicle users, following similar trajectories as cruise controls, airbags, etc. Whether the implementation of AVG continues to be market driven in the future is highly uncertain, however. In general, suppliers are likely to be reluctant to commit themselves with regard to manufacturing and servicing systems when consumer demand, technological progress, public policy support, etc are unknown (Hanson & Tsao, 1996).

Societal conditions for AVG implementation

Another source of uncertainty refers to whether specific general conditions have to be fulfilled for AVG implementation. For instance in the field of legal regulations, it might be necessary to change rules in the context of liability and third-party insurances (Van Wees, 1998). In case of AVG technology which depends on some infrastructure support, the road management authorities should bear at least part of the liability for accidents. Those authorities are for instance responsible for checks on the vehicle features concerning lane access and for taking over (parts of) the driver's responsibilities. This shift in responsibility might require new rules and arrangements with insurance companies.

Another aspect in this context concerns the legal regulation of the use of road infrastructure. For instance, in case of special AVG lanes: is it possible to exclude non-AVG vehicles from these lanes? In addition, when a specific permit system based on identity checks is required, what to do with the important issue of privacy? In the Netherlands neglect of the privacy issue was one of the reasons for not implementing a system of automated road pricing in the early nineties (De Wit & Van Gent, 1996). This brings us to the issue of societal acceptance. It is often argued (e.g. Dingus et al, 1998) that drivers will reject AVG, as it reduces the user freedom and the responsibility to make his/her own decisions. This, in turn, might result in elimination of many of the benefits from AVG. One also has to be aware of the problem that when specific groups are

preferred to other vehicles without AVG technology, for instance by offering special lanes for AVG vehicles, this might trigger a growth of societal resistance.

Many of the above mentioned aspects suggest some role for public authorities. Clearly, a top-down regulatory approach, by which public authorities for instance forbid manufacturers to implement AVG systems which might endanger traffic safety and/or oblige drivers to equip their vehicles with systems which have proven to be effective, is highly unlikely. This should require a.o. a sound, unambiguous knowledge of the relationship between AVG systems and traffic impacts and such knowledge is currently lacking. A facilitating or stimulating role of public authorities in the present fuzzy development of AVG seems to be more productive. Evidently, the specifics of such an approach depend on the specific nature of the development (kind of technology involved and kind of implementation strategy) and the related impacts on transportation as a whole. In general, a regulatory role (new legal rules) seems necessary with respect to the aspect of liability related to accidents where AVG is involved. Standardisation might require a regulatory role but undoubtedly requires a facilitating role too. A clear facilitating role is needed as far as it concerns the development of infrastructure networks. The organisation (or perhaps even orchestration?) of the process of monitoring AVG developments and additional planning and decision making, also requires an active role (facilitating? stimulating?) of public authorities. Stimulating the developments to take a route that is attractive to public transport policy requires measures based on positive incentives (e.g. financial).

To our knowledge, public authorities have been rather passive with respect to elaborating ideas about how to operate in respect to the industry pushed AVG implementation. Passiveness could lead to a situation that automobile industries gain too much influence on the transport system, because they have the technology, the market, the knowledge, etc. It is inevitable that in that case transportation developments will be increasingly based on the limited interests of those industries. Clearly, from the point of view of public transport policy, this would not be a satisfactory development. However, we are also of the opinion that automobile industries want public authorities to take their responsibility and to timely indicate the publicly preferred development of AVG technology (e.g. Reichart, 1997).

One reason is that, as has been argued, a large-scale introduction of AVG technology in road traffic could require an active role of public authorities as for creating specific conditions. Another reason is that industries do not like to be confronted with regulations after considerable R&D investments into specific directions. An anticipated thinking over the specific nature of these issues, timely decision making and public-private cooperation is in the interest of all parties.

As described in the previous section, today's role of public policy makers has mostly been limited to the one of research and development manager, mainly focusing on stimulating the exploration of technical possibilities of AVG. The aforementioned, more societal-oriented questions to answer and choices to be made, are still hardly considered. This could hinder AVG developments in an early stage or lead to the implementation of

AVG systems which serve producers and individual consumers' interests only, not more general transport policies. Hence, the research efforts on AVG technology development should be balanced with research on the non-technological dimensions of AVG implementation.

1.5 Research objectives and research strategy

Experts agree that the developments on AVG so far have been strongly 'technology driven'. In reaction, the need for innovative, technology assessment research to anticipate these AVG developments from the view of public policy (a 'society pull' approach) has recently been argued by several authors (e.g. Banister, 1994; Van Arem & Van der Vlist, 1994; Hall & Tsao, 1994; Al-Ayat. & Hall, 1994, Van der Heijden & Marchau, 1995; Baggen et al, 1995; Bristow et al 1997). The next question is how to perform this type of research.

Traditional assessment approaches used by transportation professionals in this field, mostly based on trend extrapolations and quantitative modelling, are not sufficient to cope with the different sources of uncertainty as mentioned in the previous section. These models typically focus on the physical part of road transportation, i.e. infrastructure and traffic, and hardly or not at all on the decisions made by individuals and organisations involved in transportation processes. To be more specific the theoretical assumptions underlying these traditional models are often at least disputable. Banister (1994) refers to this in his statement: ...“The real problem is one of a single sector vision which draw no linkages between transport and what is happening in society as a whole”.. (p.153). Banister argues that the traditional rational analytical processes in research and planning have insufficiently been adapted in terms of concepts and tools to the situation where many of the decisions are not matters of professional expertise but of matters of opinion and political values rather than facts. Transport planners have... "tended to remain neutral rather than play a significant role in decision making. They have cocooned themselves with a commitment to a technocratic role in transport planning and have restricted themselves to the relative comfort of expert advice"... (p. 129). Consequently, their impact on policy formulation has been lessened and the establishment of robust long-term approaches to the ever-growing transportation challenges becomes less easy. Moreover, there are too few incentives to change the dominant application of traditional planning models and technical forecasting models. The researchers, using these models, are pre-occupied with quantification on behalf of aggregate statistical-empirical analyses. These professionals assume that they have sufficient insight into the complex system to accurately model the systems structure and to predict the future with sufficient accuracy: uncertainty tends to be neglected. This brings us to the formulation of the research problem addressed in this study, which can be summarised in terms of:

the lack of an analytic approach for the better understanding and the reduction of uncertainty on future AVG implementation

Uncertainty is inherent in the dynamic nature of technology development, the dynamics in the transport system as well as contextual changes in the transport sector with regard to e.g. economic, environmental and social fields. Banister as well as other authors (e.g. Van der Heijden, 1995) stress the need for a more multi-disciplinary, multi-method approach, based on integration of quantitative and qualitative research. The field of interdisciplinary research on the possibilities and consequences of technology implementation in general is Technology Assessment (TA). TA can be considered as a specific form of policy analysis that focuses on the study of technological developments in order to support policymaking (e.g. Porter et al, 1980; Mayer, 1997). TA aims at identifying the societal meaning of technological concepts and relates this meaning to new technological development paths being more in line with societal needs and problems (Grin & Van der Graaf, 1996). Hence, this school of research is, logically, of interest for this thesis. However, the field of TA is broad, varying from the more traditional technology forecasting and impact analysis up to the specification of strategies to influence technological courses. A variety of TA concepts and methods has emerged over the years out of practical problem situations. Consequently, TA does not offer a clear body of scientific knowledge which enables us to select straightforward a particular concept and method to tackle the research problem within this thesis. Hence, from a scientific point of view the challenge is to develop and use an approach that is appropriate in this context. This challenge is the main objective within this thesis. The research objective is:

the specification, operationalisation and application of an innovative TA approach to identify and reduce the uncertainty of future AVG implementation.

Evidently, the term future has to be further specified in terms of the time horizon to be considered. In this thesis we adopt, for a first focus, the time horizon that is generally used in the professional debate about AVG, which is 2020/2025. Later, we will argue that for generating more detailed statements on AVG development a shorter-term focus (10 years) is required. The accepted limiting in horizon will be based on further explorations in Chapter 5.

In order to realise the research objective, we will focus on the following research questions, formulated from the perspective of public interests:

1. *What methodological approach can be based upon the field of TA to cope with the uncertainties regarding future AVG implementation?*
2. *(a) How can the long-term uncertainties be better structured in order to allow for more in-depth analysis of plausible developments for the medium term (up to 2020/2025)? (b) What are the results of this analysis?*
3. *(a) How can conditions of plausible technology applications for this time period be analysed in-depth? (b) What are the results of this analysis?*

4. (a) *How can the likeliness of these developments be explored, from the perspective of crucial stakeholders, for a successful, near-term implementation?* (b) *What are the results of this analysis?*
5. *What conclusions can be drawn with regard to the role of public authorities in relation to AVG development?*

The results should provide knowledge on the societal consequences of the implementation of AVG technology to public authorities involved, in order to support the development of their policy strategy and to identify important issues for follow-up, in-depth research. In order to answer the research questions the research strategy followed throughout this thesis is from general (broad) to specific (in depth), from long term to short term, and from the technological possibilities to the implications for the process of implementation.

In particular *Chapter two* explores the general field of Technology Assessment to specify a conceptual approach to cope with the various sources of uncertainty for implementation of AVG. A 'backcasting' approach is considered to be appropriate, in which future AVG concepts are constructed and evaluated systematically in order to eliminate those concepts which are both technical and societal unlikely to become implemented in the future.

In *Chapter three* hypothetical, possible AVG concepts are constructed and plausible concepts selected.

In *Chapter four* and *five* the future of and conditions for these plausible concepts are studied in terms of technical and non-technical barriers to implementation. In chapter four the methodological approach to perform this research is given. In chapter five the results of this study are presented in terms of likely development of AVG concepts and related conditions.

In *Chapter six* and *seven* the preferences of relevant stakeholders for early AVG concepts are studied. Chapter six focuses on the choice and operationalisation of a methodological approach to model these preferences. In chapter seven the preference models are presented and analysed.

Finally, in *Chapter eight*, the overall results of this thesis are presented and discussed from the perspective of the public interests.



Chapter 2.

A conceptual approach for Technology Assessment AVG

2.1 Introduction

In this chapter the field of Technology Assessment (TA) is explored with the aim to specify a methodological approach to cope with uncertainty of future AVG implementation. In section 2.2 different TA styles, TA methodologies and specific methods used within TA studies are presented. It appears that choices made for a specific TA style as well as for methodological approaches used are typically 'problem driven'. Consequently, in section 2.3, the problem field in this thesis is first considered in-depth, according to a system view on the functionality of AVG. Next, the methodological approach applied in this thesis is elaborated in section 2.4.

2.2 The framework of Technology Assessment

The way in which technologies develop as well as the possibility to influence technological developments is dominantly researched within the field of Technology Assessment (TA). In general, TA is focusing on the evaluation of the nature and development of technology in a broad sense.

The origin of TA dates back to the fifties. In those days technology forecasting studies were performed in order to support policy decisions on technological investments of large industries and governments. In the sixties the need for a better anticipation of technological developments was stimulated by the increased complexity of technologies and the growing awareness of negative impacts of technological developments (Vary T. Coates & J.F. Coates, 1989). Consequently, the nature of technology forecasting studies changed into technology assessment studies: studies assessing the intended as well as the unintended impacts of technological developments on society. These studies have become well-known these days as early warning TA or Awareness TA (ATA).

"Technology assessment is an attempt to establish an early warning system to detect, control and direct technological changes and developments so as to maximise the public good while minimising the public risks" (Cetron & Connor, 1972: p. 2)

These early TA studies implicitly relied on technological determinism, i.e. technological developments were assumed to cause societal change. Technological determinism presumes that technological developments are not controllable by its societal context, as technology has its own internal dynamics. Therefore, according to this view, technological developments can at most be accelerated or decelerated by for instance regulations or incentives. TA assumed the ability to objectively forecast technological developments and all of its societal impacts. Initially, ATA was an instrument for all those who criticise the development of a technology. Later on, TA became more and more an instrument for selected actors, like, for instance, public policy makers or specific private companies. In the United States this even resulted in the establishment of the Office of Technology Assessment (OTA) in 1972, which lasted until 1995. The OTA explored complex issues involving technology in order to help the Congress to identify policy options and answers regarding technological developments. Consequently, the OTA defined TA in particular as a policy instrument: "... TA is a form of policy research, which provides a balanced appraisal to the policy maker. Ideally, it is a system to ask the right questions and obtain correct and timely answers. It identifies policy issues, assesses the impact of alternative courses of action and presents findings. It is a method of analysis that systematically appraises the nature, significance, status and merit of a technological programme ..."

(Daddario, 1968).

In the seventies and eighties TA broadened from strictly forecasting the (un)intended impacts of technological developments on society towards developing strategies to

influence the technological developments in an early stage to meet societal desirable goals. This was related to shifting paradigms on technological innovation and diffusion processes.

In this period the validity of the assumption of technological determinism became increasingly criticised. Experience and research indicated that technological developments were often not autonomous but strongly interact with its social context (Bijker et al, 1987). Forecasts often appeared to be wrong or technological developments unforeseen. For instance, Ascher (1978) gives examples of forecasting errors within various domains, including transportation.

Consequently, new paradigms have been suggested on technology development, which claim to be more appropriate. Within these paradigms it is stated that technology development is more or less influenced by societal needs and values. Some researchers even assume some technology developments to be a result of the social actions and social strategies of different societal groups involved in or affected by the technology development (e.g. Pinch & Bijker, 1987). Technology development is seen as a 'social construct' within this context, in which more and more people become interdependently involved during a technology development. More compromise-views on technology development have also been described, considering technology and society highly interdependent. Nor technological progress nor societal needs and values are considered to dominate exclusively future technological developments by this paradigm. For instance, Porter et al (1980) in this context state that .. "a relationship of mutual causality exists between technology and society" .. (p. 24).

These shifting paradigms on technology development have influenced the context and methodology of TA. The belief that, by scientific research, it was possible to objectively determine future technological developments and all of its societal impacts, was relaxed. Furthermore, the perception of the nature of decision-making processes regarding technological developments and the use of TA findings in these processes, changed (Smits & Leyten, 1988). The assumption that decision-making follows a rational-analytic pattern in this context appeared unrealistic. TA practice pointed out that decision making processes regarding innovative technologies are much more diffuse, and political rationality (might) play an important role. It became clear that more attention was needed to match the relationship between the TA process and the decision-making process served by the TA.

Summarising, the role of TA has been adjusted to the process of technology development, i.e. shaping future development processes of technologies (Van den Ende et al, 1998). This new TA paradigm was described by Smits and Leyten(1991) as follows:

"Technology Assessment is a process consisting of analyses of technological developments and their consequences, plus the discussions in response to those analyses.

The goal of TA is to provide information to people involved with technological development in order to help establish their strategic policy"(Smits and Leyten, 1991: p. 340).

Some new TA styles have emerged out of this paradigm. For instance, Strategic TA (STA) involves the studies and activities to support a specific actor or policy sector in developing an appropriate strategy for a certain technological development (Smits & Leyten, 1991). A related style to STA is Constructive TA (CTA) which intends to incorporate societal aspects and desires of actors into the design of new technologies. The process of new technology development is broadened in this way and the assessment methods required and actions taken to construct new technologies are labelled as CTA (Rip et al 1995). A basic characteristic of CTA is the attempt to reach a common view between different actors on the experienced problem, the desired future, and the strategies to reach this future. In summary, nowadays the following TA styles can be distinguished, having different aims (e.g. Moon et al, 1998):

- Awareness TA: focusing on providing forecasts and impacts of technological developments. ATA often has an early warning function to the public at large, regarding technological opportunities and threats;
- Strategic TA: focusing on the provision of structured knowledge for specific decision makers concerning both the process and the contingency of the technology development. Furthermore, STA often aims at initiating the start of a debate among stakeholders;
- Constructive TA: focusing on the process architecture of technology implementation. CTA emphasises on the dialogue among and involvement of stakeholders to initiate new technological avenues.

The number of methods used for performing this variety of technology assessments is both large and diverse. Van den Ende et al (1998) structure this variety in a useful way in a recent publication. The classification of methods as described below is partly based on this article and presented in Table 2-1 together with some examples.

A first distinction can be made between the assessment methodology used for the TA and the particular methods used within the TA. The methods used within a TA aim at studying a specific aspect related to the TA problem. The assessment methodologies aim at integrating the different aspects of the technology studied and/or the decision process to be addressed. They often focus on the actions which have to be taken in performing an assessment, i.e. how to do the technology assessment. The assessment methodologies and methods together establish the methodological approach of the TA.

A second distinction regarding the assessment methodologies and methods used in TAs can be made according to the aim of the technology assessment: analysis, intervention or reflection. The category of 'analysis' refers to various analytical assessment methodologies and methods being used in technology assessment studies throughout the years. The second category includes intervention methodologies and methods used to intervene in decision processes on technology development: heuristics for intervention in decision processes on technology development. The category of reflective methodologies and methods is used for

Table 2-1: A taxonomy of Technology Assessment methodologies and methods

TA aim	analysis	intervention	reflection
TA approach			
assessment methodology	technology forecasting backcasting analysis impact assessment cost-benefit analysis scenario analysis market analysis	interactive TA consumer CTA strategic niche management	structured reasoning historical case research
assessment methods	analogies monitoring trend extrapolation modelling policy capture structured interaction	consensus conference interactive workshops gaming	workshops interviews literature surveys

the organisation of the decision- and development process in such a way that societal desires are incorporated in this process.

The relationship between TA styles, TA methodologies and TA methods is sometimes obvious, whereas for other cases this is not. We will briefly elaborate on these relationships according to the structure as presented above (see Table 2-1):

- Methodologies for analysis include technology forecasting, the identification and evaluation of impacts, market analysis, cost-benefit analysis, and so on. They are used within all TA styles, although they have a different interpretation depending upon the TA context within which they are used. For instance, technology forecasting in terms of predicting the future development of technologies aims at clarifying what will happen in the future. These forecasts are strongly related to ATA as they focus on specifying the future development of a technology. These forecasts do not include activities to organise the process of technology development. Technology forecasts are also used in STA and CTA, but in those contexts forecasts focus on to what might happen in the future as well as on the conditions and decisions needed to achieve this future.

Other assessment methodologies for analysis have been used which focus on the ways to intervene and influence a technological development. Consequently, these approaches are related to the process types of TAs (STA and CTA). For instance, backcasting is such an assessment methodology for analysis being under growing interest. In general, backcasting involves the identification of a desirable future and stimulates the development of certain innovation processes based on this desired future.

Several methods for analysis are used within TA studies. Overviews and detailed descriptions of these methods can be found in several textbooks (e.g. Porter et al, 1991; Martino, 1993). Examples include methods to elicit opinions of experts or other relevant actors on future technology development in a structured, interactive way (e.g. brainstorming, Delphi technique), modelling technology innovation and diffusion, trend extrapolation methods, scenario construction, modelling stakeholders' preferences (policy capture), etc.

- TA methodologies for interventions are mainly used in the process-oriented styles of TA (STA and CTA). A methodology which has emerged over the years is interactive or participative TA: future stakeholders of innovation processes are consulted in an early stage to incorporate their desires into the development of the technology. Interactive TA involves an iterative process of debates among stakeholders in which the perceptions, views and preferences of different stakeholders regarding a problem situation and potential technological solutions are elicited and discussed in order to influence the technological course into a direction desired by the stakeholders (Grin et al, 1997). A specific form of interactive TA is consumer TA which aims at incorporating the desires of future consumers regarding a technological development. Another methodology for intervention is strategic niche management. This involves the implementation of a technology within a protected environment in order to stimulate technology acceptance and improvement.

Specific methods for interventions include consensus conferences, interactive workshops and gaming (Schot, 1996). These methods are typically used within interactive TA for supporting the debate among participants.

- Reflective TA studies serve improvements of the decision- and innovation implementation process which incorporate societal desires in this process. There are no specific methodologies which support the set-up of reflective TA's. One often has to rely on structured reasoning and historical case studies, in which the determining factors for technology development are identified. This identification then forms a base for intervening in the technology development. The reflective methodologies clearly refer to process-oriented TAs. Furthermore, these studies involve the evaluation of TA theories and approaches. Examples of reflective methods are workshops, interviews, literature research, etc.

Now that the field of TA has been structured in terms of TA styles, assessment methodologies and methods, the question is which TA style and which TA approach, in terms of assessment methodologies and methods, is most appropriate within the context of reducing uncertainty regarding AVG implementation?

The choice of a TA style is related to the knowledge assumed to be sufficient to shape future technology implementation in a societal desired way: (a) only contingency knowledge is needed on the technological development (ATA) (often implicitly assuming that technology development is dominated by technological progress); (b) a mix of knowledge is required on both the content and the organisational dimensions of technology

implementation (STA) (implicitly assuming that technology development is dominated by a mix of technological progress and societal acceptance); or (c) knowledge is basically required on the organisational dimensions of technology implementation (CTA) (implicitly assuming that technological development is constructed by societal acceptance).

Once the style has been chosen, we have to choose a TA approach. This choice is determined by the aim of the technology assessment: analysing the technology development, intervening in the technology development or researching the ways how to intervene in the technology development. In this thesis the aim is to identify and reduce uncertainty regarding the implementation of AVG technology. Hence, in terms of the above defined classification, the methodologies and methods for intervention and reflection are not of interest for our research. In terms of the classification of TA approaches as presented above, the research in this thesis points at methodologies and methods for analyses.

As argued above, the analytical approach is used within all TA styles and encompasses various assessment methodologies and methods. Unfortunately, there hardly is any scientific knowledge for making choices between different analytical assessment methodologies and methods (Porter, 1995). No criteria have been developed for these choices as most TAs have been developed in practice and few practitioners have reflected on their choices made (Van den Ende et al, 1998). In general, it seems that the choices made for a specific technology assessment study are typically determined by the problem encountered by the assessor and the objectives of study (Langenhove & Berloznik, 1998).

Summarising, the TA researcher is forced to make her/his choices within the general framework as presented above. Hence, the lesson learned is that one first has to specify the information needs, then has to decide on the TA style, next choose the assessment methodology and finally the method(s) to be used. In particular we have to answer the following three related questions:

1. Which TA style is most appropriate to study the uncertainty of future development of AVG technology?
2. Given this style, which TA assessment methodology (for analyses) is appropriate to reduce uncertainty regarding AVG implementation?
3. Which TA method(s) (for analyses) can be used in order to perform this reduction?

We already reflected on the thoughts behind the choice of a specific TA style. The choice of a specific, analytical TA approach basically depends on whether one might assume that future AVG developments are likely to be characterised by a continuation (i.e. extrapolation) of the past or that certain discontinuities or surprises might appear in the future affecting the technological development substantially. If future surprises cannot be excluded in advance, the probable nature of these discontinuities should be examined further, i.e. both technological and societal or mainly societal. As such, the relationship between AVG technologies and the transport system needs to be studied in terms of the possible dynamics of future AVG implementation and the causal mechanisms underlying these dynamics. We will address this issue in the next section.

2.3 Understanding the dynamics of future AVG implementation

In order to study the dynamics of future AVG implementation adequately, a systematic exploration of the AVG technologies, the transport system as well as the relationships between them is needed. In subsection 2.3.1, a system view on AVG and the transport system is presented. Next, in 2.3.2, the dynamics of future AVG implementation and underlying mechanisms are identified according to this view.

2.3.1 A system view on AVG technologies and the transport system

In general, AVG is known as ‘the partly or totally taking over of the vehicle driving task by information and communication technology’. By this definition AVG encompasses a variety of systems. This variety can be structured by using a general framework presented by Hall (1995). According to this framework, each AVG system is based on three principal entities: the vehicle, the driver and the road infrastructure. Each entity contains five basic devices which have to cooperate to perform the vehicle driving task. These devices are sensors, intelligence, memory, transmitters and actuators. In Figure 2-1, a schematic representation of the way in which these devices cooperate is illustrated. Sensors are devices that collect information by observing driving conditions and/or by receiving messages from, for instance, other vehicles, the road infrastructure, road-operators, etc. This data is next processed by the intelligence, a device that formulates commands and composes messages, based on a set of interpretation heuristics and decision rules. The knowledge and experience of the entity are stored within the memory. The information from the intelligence is transformed into actions by the actuator and transformed into

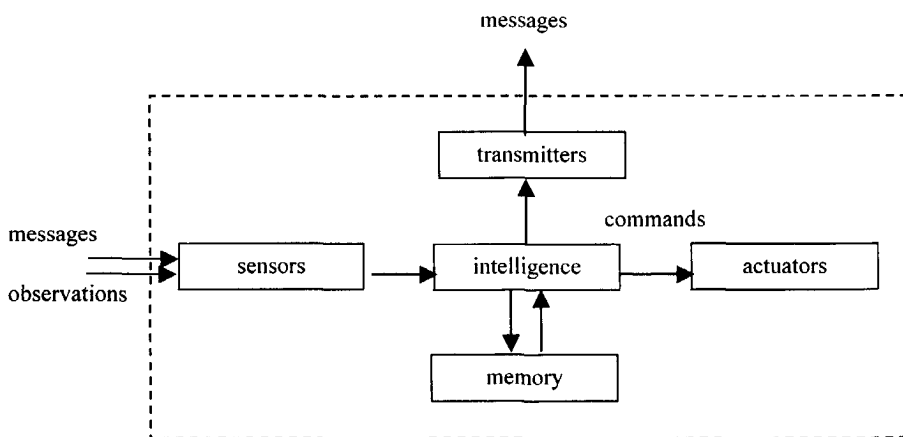


Figure 2-1: The basic devices of AVG

relevant messages by the transmitter.

Today's driving is mainly based on human sensing, decision making, transmitting and actuation. However, some systems have already become rather normal features of car control, e.g. antilock braking systems, traction control, etc. These systems can be regarded as predecessors of AVG systems: the sensors of such systems continuously guard the roadholding between vehicle tyres and road surface and, in case of potential skidding, the driver input is overridden by an appropriate brake control command.

Various AVG systems can now be constructed by typical combinations of varying capabilities of each device. Sensors can collect data on, for instance, the state of the driver, the state of the vehicle, obstacles in the vicinity of the vehicle, the roadway conditions, the traffic conditions, etc. (Komoda & Goudy, 1995). The intelligence and memory form the heart of the entity as here decisions are made for executing specific actions, related to the specific system objectives (e.g. vehicle-following, lane keeping, lane changing/lane merging). Regarding the actuators there are various options for both the sort of actuator and for the level of actuation. The sorts of possible actuation are related to the control devices present within a vehicle, i.e. transmission, throttle, brake and steer. Regarding the level of actuation, drivers could for instance be provided with information or instructions. Information can be given in several ways, e.g. acoustic, visual, and haptic. Another option is to initiate some control by the system, which can be overruled by the driver. Concerning the transmission of messages, systems can be distinguished which are totally self-supporting or autonomous and systems which cooperate, i.e. communicate, with other entities.

Various combinations of these system elements are currently worldwide studied, tested and improved. They relate to the following well-known user functions (e.g. Shladover, 1995; Diebold Institute, 1995; Miyazaki, 1995; AHSRA, 1998):

longitudinal collision avoidance: refers to systems which scan the road ahead for vehicles or obstacles. When found, the possible danger of crashing is determined and, if so, a collision avoidance action is taken, e.g.:

- rear-end crash warning and control
- speed headway support
- head-on crash warning and control
- passing warning and control
- backing crash warning

lateral collision avoidance: refers to systems which scan the roadway and direct environment beside the vehicle. In case of a potential collision between two vehicles in adjacent lanes or imminent danger of road departure, crash warning and controls are provided, e.g.:

- lane keeping warning and control
- lane change collision warning and control

intersection collision avoidance: supports the driver when approaching or crossing an intersection by warning the driver for possible collisions.

vision enhancement for crash avoidance: improves the visibility of the driving scene by providing direct visual information of potential obstacles in the roadway.

safety readiness: observes and evaluates the state of the driver, the vehicle dynamics and operational status, and the condition of the immediate roadway surface. In case of degraded conditions, warnings and controls are provided, e.g.:

- impaired driver warning and control override
- vehicle condition warning
- in-vehicle infrastructure condition warning
- intelligent speed adapter

integrated systems: combines different user functions as mentioned above, e.g.:

- automated highway systems

Note that this list is not exhaustive in terms of including all AVG systems currently researched and developed. The developments of AVG systems are going rapidly and an important part of these developments takes place within the private sector. Electronics and vehicle industries are not often willing to publish about the systems they will bring on the market due to market competition. This makes it difficult, or even impossible, for researchers to be exactly informed about the specific operating characteristics of AVG systems of interest.

In this thesis only those services are considered which are basically essential for establishing a situation of fully automated driving. Hence, the systems for longitudinal collision avoidance, lateral collision avoidance and automated highways are of primary interest. Many of these systems are not primarily subject to large-scale market introductions and the limited information on detailed operating characteristics of these systems imposes less problems for research.

As stated above, the next step involves studying the relationship between these AVG technologies and the transport system. In particular we are interested in the possible dynamics of future AVG implementation and the causal mechanisms underlying these dynamics.

In order to identify the possible future dynamics regarding the implementation of these systems in the transport system, a workable structuring of the transport system would be helpful. Various structuring principles have been used in literature in the past decades. Several models of transport systems can be found in the literature, differing in point of views and aims of the architect of the model. Infrastructure network models, for instance, are oriented to the physical components of the transport system, i.e. roads and traffic flows, whereas transport economists focus their models on the tensions between transport supply and transport demand. Of course, these different views may be useful but too limited from a

public policy perspective. Public policy is concerned with intervening at the different components in a coordinated strategy for which both the interaction among the physical elements of the transport system and the behavioural mechanisms underlying this interaction are of interest.

It appears that none of the available models seem to fulfil this requirement and hence a system view has been adopted for the policy domain of traffic and transport, based on synthesising existing models (Hoedemaeker & Marchau, 1995; Van der Heijden, 1997; Van de Riet & Egeter, 1998). Basic within this view is that the transport system can be seen as a system which consists of four physical components (see Figure 2-2): potential subjects of transportation, manifest subjects of transportation, vehicles or transport units and infrastructure. Furthermore, between each of these components interactions exist which can be regarded as a market, i.e. the dynamic interaction between potential supply and demand. The result of this interaction between supply and demand is threefold (Riet & Egeter, 1998): a realised supply, a realised demand and an allocation of demand to supply. In particular the following markets are specified according to this view: the transport need market, the transport market and the traffic market.

The *transport need market* represents the interaction between the latent demands of individuals for performing specific spatial separated activities on the one hand and the transport, financial and temporal possibilities available to fulfil this need on the other hand, resulting in an actual transport demand. The potential need for transport results from the spatial, social, economic and temporal organisation of society.

The *transport market* represents the interaction of the actual transportation demand over space and time and the transportation services provided, resulting in the transport performance or mobility patterns in terms of trips made, modes used and routes chosen within a certain time period. The transport market focuses on the logistic organisation of

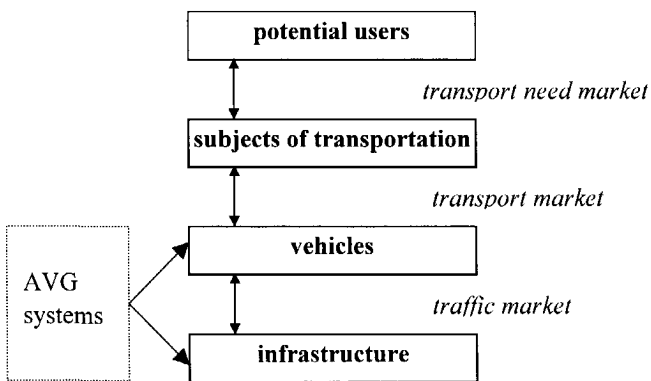


Figure 2-2: The transport system

physical transport. In this market transport companies specify logistical services in terms of the use of certain transport modes, with a certain capacity and price, at specific times and routes, in order to transport passengers or freight. Furthermore, individuals make choices of a certain transport mode and a specific route at a certain time.

Finally, the *traffic market* represents the interaction between means of transport or vehicles and the supply of infrastructure facilities. The output of this market results in the traffic patterns, the allocation of vehicles to infrastructure networks in time and space.

Characteristic of this system view is that the physical elements of the transport system are linked to the decision making of actors involved in transportation. These actors typically operate at the markets. Therefore, these markets can also be interpreted as so-called arenas of actors, characterised by decision-making, negotiation, planning, etc. Furthermore, the dynamics within these markets is based on the underlying decisions of parties involved in transportation processes. Finally, underlying system components are facilitating processes at upper laying levels and in reverse direction; processes at upper laying levels have functional requirements to underlying components.

The system view used here can be used for researching the relationship between all kinds of telematics applications being currently developed and/or implemented, and transportation. This relationship has been elaborated in (Van der Heijden & Marchau, 1998). Different types of telematics systems, in terms of functionalities and objectives of these systems, have been related to different layers of the transport system. Therefore, these systems also have different impacts.

Consider for instance the telematics which refer to the transportation need market. Important for this market are for instance tele-services (tele-working, tele-banking, tele-shopping, etc.). These services can, when sufficiently accessible to potential users, significantly reduce the need for physical transport or change activity patterns over time.

Other telematics are used for the support of logistical planning (transport market). The societal challenge is to achieve a substantial shift towards environment-friendly travel modes as well as an optimal spatial and temporal use of infrastructure networks by influencing pre-trip decision making. A substantial reduction of the use of cars and trucks in favour of train, bus or barge implies an increase in use of safer transport modes. Telematics can contribute to these aims by providing decision makers with information about route planning and modal choice. In general we see an increasing use of telematics systems supporting operational logistical decision making, such as tracing and tracking systems used to control freight transport or passengers.

Within the traffic market, several systems for supporting traffic management have been implemented. In situations of high infrastructure capacity use, traffic managers intend to influence traffic flow behaviour within infrastructure networks. A variety of systems has been developed to support the guidance of road traffic with respect to speed, access to networks, lane use, etc., basically to improve the use of the infrastructure capacity, to reduce the probability of accidents and to reduce congestion.

AVG technology is basically intervening at the levels of the vehicle and infrastructure components as has been indicated in Figure 2-2. The basic challenge is to improve vehicle

control and thus optimise the interactions between driver and vehicle. The aim is to reduce the complexity of the driving task and to eliminate possible sources of confusion. In consequence, it is assumed that this technology contributes to a more steady traffic flow and as such a better capacity use and less fuel consumption.

Consequently, we have to focus on the lower layers of the transport system, knowing that what happens there is also influenced by decisions made at higher layers. These decisions, however, will be regarded as external decisions with respect to the dynamics of future AVG implementation studied here.

2.3.2 Possible dynamics of AVG implementation

Given the afore-described system view on the relationship between telematics applications and the dynamics within the transport system, the next step is to analyse the possible dynamics of the implementation of AVG technologies within the transport system. The degree of dynamics refers to the range and sequence of future states of the different transport system components and markets when AVG technology is implemented. In May 1995 a meeting was organised within the TRAIL Research School among Dutch experts to give a first insight in this range (Baggen et al, 1995). Experts from different fields (e.g. policymakers, scientists, consultants) were invited to express and discuss their opinion regarding the possible issues they judged important in the context of future AVG implementation. In addition, recent literature was scanned to analyse the (international) state-of-the-art in knowledge on the relationship of AVG technologies and transport systems components and markets. It resulted in the following findings:

- infrastructure level: there are various infrastructure adaptations which could facilitate or even be essential for improving the traffic system in relation to in-vehicle systems. The transmission of information about actual infrastructure conditions (e.g. rain, snow) to in-vehicle speed adaptation devices could for instance increase traffic safety and efficiency significantly. Next, there are the types of roads for which AVG systems are likely to become available. Most technology is developed for use on motorways or even on specific lanes which only allow AVG vehicles. However, the traffic situation at these road types is relatively easy as compared to, for instance, urban and rural roads: the traffic on these roads is homogeneous, the roadway curvature is limited and the road boundaries are clearly set. Consequently, supporting vehicle control seems the least complex challenge for this road network as compared to other road networks.
- traffic market level: currently, in what way AVG systems will affect traffic flow behaviour and therefore indirectly traffic safety and road efficiency is unclear. Although, in general, AVG intends to improve traffic efficiency (or at least not to reduce road capacity), there are studies which forecast capacity decrease by certain penetration degrees of some systems (Van Arem et al, 1996). Furthermore, safety benefits could be counteracted by behavioural adaptation of drivers (e.g. Gundy,

1994; Endsley & Kiris, 1995). These negative efficiency- and safety impacts increase in case of a mixed situation of vehicles with different systems, each having its specific type of support and performance. In addition, the relationship between AVG systems and environmental impact is unclear. For instance, some system configurations suggest positive impacts on emissions, whereas others might indicate the opposite (Horan, 1994). This opposite impact might be caused by an increased attractiveness of the car for particular driver categories (e.g. the elderly). This might generate more vehicle kilometres and thus more use of fuel and less emission reductions.

- vehicle level: the question which specific in-vehicle systems will significantly improve the vehicle driving quality is still open. Many system functionalities are possible, based on varying capabilities and design parameters of system elements. Take, for instance, systems supporting collision avoidance, based on electronic recognition of critical traffic situations. A wide range of available technologies is used to build potential countermeasures related to different crash types (Wassim, 1994). Systems supporting, for instance, avoidance of longitudinal collisions need another kind of sensors than systems supporting lane keeping. Furthermore, for each specific crash type several sensing options, decision-making algorithms, and types of control are possible. Finally, communication between vehicles and/or between vehicles and the road infrastructure could improve AVG system operating performance in terms of less complex sensor system and reduce the occurrence of false or nuisance alarms (Shladover, 1997).
- transport market level: the implementation of AVG systems could negatively influence existing travel behaviour in terms of a modal shift and route choices in favour of AVG. As for instance equipped vehicles will become safer, car usage could become more attractive than public transport (Banister, 1994). Consequently, more vehicle trips might be undertaken, counteracting initial safety benefits. Route choices could be influenced by the fact that a system can, for instance, only be used at a certain type of road, for reasons like e.g. improved travel time, safety, or comfort. Hence, the long-term influence of AVG on travel behaviour might countermeasure short-term traffic impacts.
- user level: there are several user groups for which AVG technologies could become available, as different systems providers might focus on different market segments. Collision warning systems for front and rear obstacles, for instance, are currently delivered for heavy trucks and school buses in the United States. As for cars, the upper class of the market seems to become the first user group. Currently, speed headway support is marketed for luxury vehicles only. Hence, it seems that most of the first-generation support systems will become available just for specific groups. Next, the speed of technology adoption by other groups is uncertain. For instance, in

the Netherlands antilock braking systems are rapidly becoming common features of vehicles. This could also be the case for AVG systems.

- transport need market level: the implementation of AVG systems could very well influence activity patterns in the longer run. As choices with respect to e.g. locations for living, working, shopping or recreation are also based on their qualitative accessibility, new patterns of activity could originate from the significant transport quality improvements to be induced by these systems. It has been found, for instance, that AHS has the potential to influence land use patterns significantly (Stevens et al., 1995). For instance, residential and business areas could become more decentralised, as AHS will reduce travel time.
- potential user level: AVG systems could easily generate new transport needs. For example, elderly and disabled people could be attracted to more car trips if their driving abilities improve by these systems. Freight operators and public transport operators could be interested to start or expand road transport activities due to AVG-induced improved traffic performance. In the Netherlands, for instance, innovative AVG concepts as Combi Road (freight) and people movers (public transport) are currently developed.

Apart from these developments relevant to public policy, perhaps other factors can be identified which might influence the implementation of AVG. However, the lesson is that future, large-scale implementation of AVG could develop in various ways, and as such is highly dynamic. The implementation of AVG at one specific component/market level of the transport system has implications at all other levels of the system. Due to all kinds of dynamic feedback and (sometimes) autonomous mechanisms, future AVG performance can only be analysed in-depth under strict, often not realistic, assumptions. Consequently, robust, ex ante evaluations of implementation of AVG are difficult to be made in the context of public policy making, and therefore precise decision making and strategy development is still far away. In summary, the overall dynamics of future implementation of AVG technologies is substantial and caused by:

- the dynamics in the transport system intervened, caused by the variety of conflicting objectives, problems, problem owners and policy sectors involved (Mannheim, 1984);
- the dynamics of the intervening instrument, here specifically the dynamics in technology introduction and penetration;
- transport sector contextual changes in e.g. economic, environmental and social fields.

With respect to AVG, this implies the need for answers to two basic questions:

- which AVG systems should (given general transport policy goals) or will (given AVG technological developments) be implemented? A question that is related to the lack of knowledge of AVG system performance and impacts of AVG implementation on a large scale in the transport system;
- how should (given general transport policy goals) or will (given AVG technological developments) AVG systems be implemented? A question that is related to the lack of knowledge about the preferences and choices of parties involved in or affected by AVG implementation.

Both questions are, by nature, strongly related and allow for a wide range of answers. Therefore, the choice of a TA style and the specification of an adequate TA approach requires an explicit handling of these ranges as well as studying the relations between them. Such an approach will be conceptualised in the next section.

2.4 Conceptual approach

In section 2.2 we formulated the following three questions which had to be answered to specify a TA style and a methodological approach:

1. Which TA style is most appropriate to study the uncertainty of future development of AVG technology?
2. Given this style, which TA assessment methodology (for analyses) is appropriate to reduce uncertainty regarding AVG implementation?
3. Which TA method(s) (for analyses) can be used in order to perform this reduction?

Regarding the choice of an appropriate TA style, in the previous section it was indicated that contingency knowledge on AVG technological development only is unlikely to be sufficient to shape future technology implementation in a societal desired way. Hence, an Awareness TA style seems not appropriate. Furthermore, there is a need to operationalise TA styles which link contingency information on AVG technology development with information related to the determinants of the process development, i.e. future decision making of actors/parties involved. This need is due to the *dynamic interaction* between technology progress, the specification of societal goals and the acceptance by markets. These interactions deal with balancing R&D and marketing, public responsibilities, economic interests and individual needs. In terms of the TA-styles presented in section 2.2, therefore, a Strategic TA (STA) style seems appropriate.

Having decided on the style of TA, the next step involves the operationalisation of an analytical assessment methodology for the TA study (question 2). As argued in section 2.2, this operationalisation is related to the assumptions one has regarding the future character of AVG technology development. The often applied assumption that the mechanisms that

determined the historical development of the technology will also structure future development, should be relaxed. The idea of a discontinuous development cannot be eliminated. For instance, because application of the new technology will cause a breakthrough or acceleration in applications or because different conditions need to be fulfilled simultaneously before innovation will become possible. In these cases unexpected mechanisms might occur and knowledge building on future technology development should reckon with surprising trend changes. The mechanisms within the transport system which could influence the implementation of AVG point out that the absence of surprises in the future cannot be assumed. Consequently, the application of analytical methodologies based on extrapolations from the past might not be valid. Therefore, the frequently mentioned working assumption on the continuous, evolutionary character of technological progress and market introduction of these new technological systems should be made subject of research too.

In this thesis we adopt the following guiding principles according to which an appropriate TA assessment methodology should be conceptualised and, accordingly, techniques should be chosen:

- to start from a broad, holistic view on AVG and the transport system working towards more detailed, operating images;
- to start from long-term, societal desired developments of AVG, working backwards to feasible applications in the near future;
- to start with analysing technological possibilities, explicitly exploring the implications for the organisation of AVG implementation processes.

This methodology is inspired by what is known within TA as backcasting (Robinson, 1988). As indicated in section 2.2, backcasting involves the identification of a desirable future and stimulates the development of certain innovation processes to reach this desired future. Backcasting does not aim at prediction but at identifying conditions for different future paths that can be followed (Mulder, 1995). Whereas forecasting is attempting to elicit the most likely future under specified conditions, backcasting emphasises to determine the degree of freedom of action with respect to possible futures (Robinson, 1990).

In general, in case of backcasting, first an image is researched which might be a future solution for the societal problem at hand. If such an image can be made explicit, the next step is to identify and assess a path between that future image and today. If such an image does not exist, the path will not be explored and the image will be redeveloped and adjusted (Hojer, 1998).

The last question involves the choice of methods which can be used within the assessment methodology. An investigation of available research methods, typical of and exclusively elaborated for backcasting methodologies, appeared to be very disappointing. No such methods could be found (Dreborg, 1996). It implies that a combination of conventional methods should be applied in this context. These choices should be based on

criteria regarding the contents of the study object. This resulted in the following research steps and methods to be used within our research.

Step 1:

The first research activities are typically deal with the construction and exploration of alternative AVG images for the long term. In this study we prefer the use of the word 'concept', indicating that we try to reduce fuzziness as much as possible. In our opinion, the word 'image' allows for a more global interpretation than the word 'concept'. There is no specific procedure of constructing alternative AVG concepts. For instance, concepts can be presented by textual descriptions, pictures, etc. However, it is needed to structure concepts in such a way that they are useful for further analysis and evaluation. A general structuring method being helpful in this context is morphological analysis (Van Doorn & Van Vught, 1978). Applied to our study, it allows AVG concepts to be interpreted as combinations of particular values of AVG key dimensions. The variety in future AVG concepts is largely dependent upon decisions that will be taken with respect to:

- the instrumentation dimension: whether the technology will be vehicle-based or infrastructure-based or based on a combination of both;
- the automation dimension: whether the focus will be on gradually taking over driver tasks or on a more radical and complete taking over (e.g. because of interactions between specific tasks that cannot be disrupted);
- the market dimension: whether the new technology will be available for everybody or for a long time only for specific groups (e.g. elderly people or commercial drivers);
- the spatial dimension: whether the application of AVG technology will primarily be focused on the (international) motorway system or on all road systems within specific regions (e.g. urban agglomerations).

The variety of combinations of possible values along the different dimensions generate alternative concepts. Next, these concepts are screened to identify concepts which are highly unlikely or unfeasible. The elimination of these concepts will limit further research to a set of plausible AVG concepts.

Step 2:

Once this set has been identified, a second step in the research is to analyse these plausible AVG concepts in-depth in relation to the basic conditions postulated for each of the concepts. Research in the field of transport technology implementation indicates the importance of conditions related to (Underwood, 1990; Levine & Funke, 1995):

- the technology itself: is the required technology already available to be implemented on a large scale or will particular parts of the technology have to be developed and tested yet?

- the social-legal regulations: do the required social-legal conditions basically fit into the accepted framework in this respect? Is it likely for these conditions to be fulfilled in time or will regulations be required which have the potential to conflict with basic social-legal principles (e.g. exclusion of specific driver groups from parts of the road network)?
- traffic management: how substantial is the uncertainty with regard to the impacts of various AVG concepts on road traffic performance? To what degree and within what time period should the infrastructure be adapted? Will the assumed traffic management conditions be fulfilled?
- financial/economics: is it possible to identify the costs and benefits clearly and are they well-balanced? Is there an acceptable allocation of costs and benefits among the different parties involved in the specific AVG concept?
- social acceptability: how does the concept fit into to the basic transportation needs and behaviour of individuals?

As mentioned, the basic research task in the second step is to analyse the specific nature and necessity of the above mentioned conditions. Due to the futuristic character of AVG, empirical data is not available for this type of analysis and extrapolation from past observations is insufficient for valid forecasts. Based on previous experiences in studies on the future, the expertise and insights of experts are found to be of great potential value (Helmer, 1988). Therefore, the use of methods to collect expert opinions seems to be a valuable approach to support this analysis. There are different ways to collect expert opinions, all of them requiring a clear, meaningful and unambiguous formulation of the conditions to be evaluated to avoid the danger of 'garbage in garbage out'.

Step 3:

Evidently, the fulfilment of the conditions identified in the previous step are dependent upon actions and decisions. Therefore, the third step focuses on the question whether it is plausible that the related decisions and/or actions will be taken in time. In terms of research, it requires the identification of the parties being involved in those decisions and actions. More specifically, the willingness and possibility of those parties to act, has to be analysed.

The parties' willingness to co-operate in implementing some specific AVG concept, is strongly related to the perception by these parties regarding the contribution of AVG to the generally pursued goals with respect to transportation of people and the specific party-related interests. In other words: there exists a relationship between willingness and the basic view of the party on the system, which necessarily includes normative elements: this is what the party wants; these are the elements (standards) you have to reckon with; these are acceptable limits.

Once relevant parties and their positions have been identified, their willingness to support specific implementation AVG concepts can be assessed and more knowledge on the specific nature of the various conditions and decisions can be gathered. This third step

requires insight into the future preference and choice behaviour of stakeholders regarding AVG concepts. Hence, from a methodological point of view, this points to use of methods aimed at the collection and modelling of stakeholders' preference and choice behaviour. A variety of methods might serve this goal. The final choice is dependent upon the insight gained in the previous steps.

In summary, the conceptual approach of the TA study within this thesis is the following (see Figure 2-3):

1. *the specification of plausible AVG concepts using morphological analysis and literature review (chapter 3);*
2. *to analyse the conditions for the implementation of plausible concepts by using the opinions of experts (chapter 4 and 5);*
3. *to analyse whether stakeholders' decisions and actions related to the conditions for the implementation of plausible concepts will be fulfilled in time, using preference modelling (chapter 6 and 7).*

The approach described typically deals with problem structuring and systematic AVG concepts exploration. The research cannot be focused on eliciting the most likely AVG development, as this does not reduce the uncertainty. Moreover, there is no conceptual and empirical basis for such a choice-eliciting process. In this thesis the aim is to collect knowledge to eliminate theoretically possible AVG developments. This elimination might be based on different facts. For instance because it is very unlikely that basic conditions will be fulfilled or because a concept blockades a sound development after first implementation, or because the conflicts with (other) transportation policy goals are too severe to be solved without basic changes in political support, etc. Hence, this approach makes the reduction of the set of options for the future AVG implementation explicit. Moreover, the remaining options will be explored in terms of types and sequence of decisions, the nature of uncertainties, the position of the parties involved, etc.

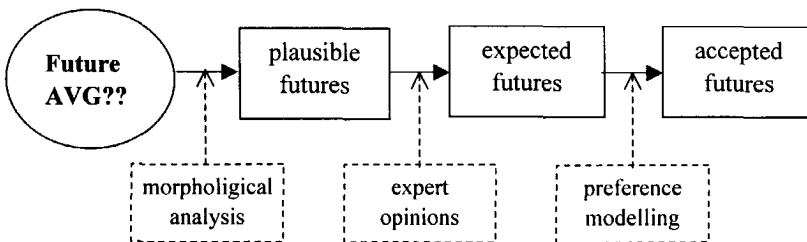


Figure 2-3: Conceptual TA-approach of this study

2.5 Conclusions

In this chapter a TA approach to reduce the uncertainty regarding AVG implementation has been conceptualised. The field of TA has been structured by distinguishing different TA styles (Awareness TA, Strategic TA and Constructive TA) and different TA approaches (analytical, intervening and reflecting). In this thesis the analytical TA approaches are only of interest, as the aim of our research involves an analysis of the technology development.

It appears that the choice of a TA style and of a specific analytical TA research approach cannot be made without having first structured and limited the issue of AVG implementation. Without structure and limitations, the degrees of freedom are too numerous and related sources of uncertainty too substantial, to choose for a particular TA style and usefully apply the more traditional, analytical TA research approaches. Therefore, we presented a research agenda bearing a more qualitative, multi-method and multi-disciplinary character.

A systematic view regarding AVG implementation points out that a TA style is needed which links contingency information on AVG technology development with information related to the determinants of the process development, i.e. future decision making of actors/parties involved. Therefore, a Strategic TA (STA) style seems appropriate. Methodologically, we furthermore plead for an approach that is based on limiting the scope of policy development and research by eliminating parts of the large variety in possible AVG developments based on a backcasting approach. This approach specifically focuses on the conditions being assumed, the related decisions and actions, the position of the parties involved and the willingness of these parties to support specific AVG implementation strategies. The result of this backcasting approach is the elimination of non-plausible and non-accepted AVG concepts and the reduction of the scope within policy making to the most promising concepts.



Chapter 3.

Plausible AVG concepts

3.1 Introduction

As pointed out in the previous chapter, the first step of research involves the specification of plausible AVG concepts. In this chapter these AVG concepts are constructed and analysed. Furthermore, the choice of the method of morphological analysis has been discussed. This method structures the concepts in such a way that they enable in-depth, further analysis and evaluation. In section 3.2 the method is presented and explained. Next, in the sections 3.3 and 3.4 this method is applied to construct theoretically possible AVG concepts and eliminate non-plausible ones. In section 0, the remaining concepts are clustered according to general expectations on the temporal nature of future AVG developments. Finally, the conclusions are drawn in section 3.6.

3.2 The construction of AVG concepts

As indicated in section 2.4, a systematic procedure supporting the construction and quick screening of AVG concepts is morphological analysis. Morphological analysis is a structuring technique by which a problem area or system concept under study is converted in terms of basic dimensions and possible values along these dimensions. A multi-dimensional solution space is constructed by considering all combinations of values (Van Doorn & Van Vught, 1978). This is called the 'morphological space' (see Figure 3-1). Due to its systematic nature, morphological analysis has the advantage that new alternatives are considered which may otherwise have been overlooked. Potential drawbacks of morphological analysis include an abundance of possibilities and human errors in judging the different options (The Futures Group, 1994). These notions will be dealt with in section 3.4. The procedure followed for morphological analysis is the following (e.g. Twiss, 1992): (a) the identification of basic dimensions constituting the variety of concepts; (b) the specification of values of these dimensions, and (c) the evaluation of all possible combinations of these values. Each of these steps will be clarified below.

The *identification of basic dimensions* is typically related to the purpose for which the concepts are used as well as to the needs and interests of the user of the concepts. The number of dimensions to be included depends on the trade-offs made by the researcher. Too many dimensions complicate the construction and presentation of concepts and too few dimensions may give an inadequate or only global description of concepts.

Within the field of AVG dimensions have only been specified to describe alternative concepts of Automated Highway Systems. Bender (1991), for instance, considers three dimensions to describe AHS alternatives. He distinguishes structural, operational and propulsion features of the system. Structural features refer to the allocation of control between the vehicle and the roadway. The operational characteristics of AHS concern, for example, vehicle entrance policy, system fleet mixture, network type, and lane separation requirements. Propulsion features include the type of propulsion as well as the distribution of the propulsion between vehicle and road. The number of dimensions was limited to those concepts that had implementation potential in the 1999-2000 period.

Initial research within the National Automated Highway System Consortium (NAHSC) considered twelve dimensions of AHS including infrastructure impact, distribution of instrumentation between vehicle and road, type of vehicles, traffic synchronisation, operating speed, control- and access strategies, etc (Stevens et al, 1995). In the following research within NAHSC, dimensions were replaced and reduced, resulting in six key dimensions used to describe AHS alternatives (Jacoby, 1997): traffic separation policy, deployment sequences and timing, distribution of intelligence and communication links, platoons or individual vehicles only, obstacle detection or exclusion and driver role(s) – overriding or intervention opportunities.

The *specification of values* of the dimensions primarily depends upon the nature of the dimensions. For some dimensions the values are restricted to two or three options. For

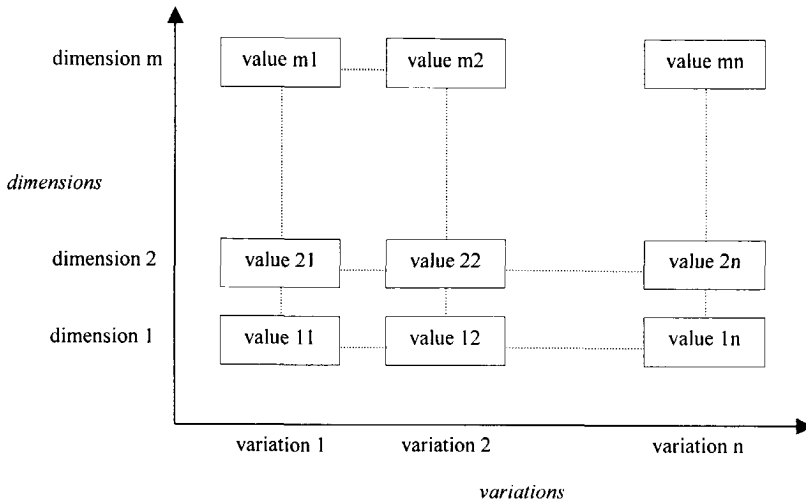


Figure 3-1: Morphological space (based on: van Doorn & van Vught, 1978)

instance, regarding the above-mentioned dimension traffic separation there are only two options: no traffic separation (between automated and manual-driven vehicles) or traffic separation, i.e. dedicated lanes. For other types of dimensions, the number of values might be much more open. Consider for instance the dimension distribution of intelligence between the road and the vehicle. The range of possible values is fixed, varying from all the intelligence in the vehicle to in all the intelligence in the road. Now it is possible to choose several values between in-vehicle intelligence and roadway-intelligence. For instance, the final AHS concepts considered in addition to the two previously mentioned extremes, three intermediate values for intelligence distribution: low cooperating vehicles, high cooperating vehicles and infrastructure support. More intermediate values can be imagined. However, an increasing number of values rapidly increases the number of alternative concepts to evaluate. For instance four dimensions with each four values gives $4^4 = 256$ alternatives. It is clear that it is often not possible to analyse very large sets of alternatives.

The *evaluation of all possible combinations of values* (the alternative concepts) should be linked to the goals of the exploration. One usually starts with selecting high-probability alternatives or eliminating unlikely cases (Porter et al, 1991). Other forms of analysis are often required to further evaluate the feasibility of alternatives and the achievement of desired goals by alternatives (The Futures Group, 1994). When the promising alternatives have been selected, some further judgements may be needed to arrive at a final set of most promising alternatives. This selection is necessary because, for instance, alternatives appear to be rather similar or not exclusive. Furthermore, the factor time may become a factor of

importance: some alternatives may exclude each other whereas other alternatives are logically expected to follow each other.

Jacoby (1997), performing the work for NAHSC, used the following guidelines to initially select promising combinations of AHS concepts:

- the choice of an alternative has a significant impact on implementation issues in terms of who builds, who pays, who operates, who maintains, overall the balance between costs and benefits;
- each alternative has a promising applicability in at least some situations;
- further analysis is needed to determine the implications and trade-offs among the options.

The work on defining and evaluating AHS concepts is useful but, for different reasons, insufficient for the research in this thesis. These concepts have been typically defined in terms of dimensions and values related to the design and operation of AHS. From a transport policy point of view the above-mentioned approach is too specific: “The first order of work must be to focus upon the definition of overall system concepts that are inherently robust in securing the reliability needed for public safety, meeting logistical needs, and fitting the socio-economic reality in which we live” (Ervin, 1995, p. 106). Furthermore, in this thesis the subject of research is not only AHS (the final picture of automated driving) but also intermediate systems, which might eventually lead to the implementation of systems which enable fully automated driving.

In order to define possible, future AVG concepts from a policy point of view, dimensions and values have to be selected which encompass all components of the transport system as affected by the implementation of AVG concepts (within the limits as defined in section 2.3). The scope should not only be limited to fully automated driving on specific motorways as, for instance, full automation might never become feasible on a large scale or motorways may appear not to be the most desired roads to implement AVG. In the following section the dimensions and values for our analysis will be specified given the considerations mentioned above.

3.3 The selection of AVG concept dimensions and values

In the previous section, it was discussed that the work performed on defining and evaluating alternative AHS concepts is useful but insufficient to define AVG concepts for our research. Therefore, the system view on AVG and the transport system as presented in subsection 2.3.1 is used to facilitate the selection process of dimensions. This system view gives an aggregate, comprehensive picture of future AVG within the transport system, in terms of physical components, their interaction via markets and the influence of decisions with various markets. It appeared that AVG technology is basically intervening at the levels of the vehicle users and infrastructure components of the transport system. Therefore, we argued that, regarding the AVG technology, the kind and degree of driver support as well

as the distribution of intelligence between road and vehicle are of primary importance. Interpreted in the context of morphological analysis, the following dimensions and possible values or states of future AVG concepts can be defined along which AVG could develop (Baggen & Marchau, 1996; Marchau & Van der Heijden, 1996):

- a *functional* dimension, representing which type of vehicle control is supported by a concept. Longitudinal and lateral control can be distinguished, as these are considered as the basic functions of automated driving (e.g. David, 1993). Longitudinal control refers to driving actions in the directions in front of and at the back of the vehicle, i.e. detection of vehicles and obstacles in the front of the vehicle and support of acceleration and deceleration. Lateral control refers to actions in the directions left and right of the vehicle, i.e. detection of lane geometry and vehicles and obstacles beside the vehicle and support of the steering task. The values considered in this context are: (1) longitudinal support; (2) lateral support, and (3) the combination of longitudinal and lateral support.
- An *automation* dimension, representing the level of driving control. For the level of control a concept can initiate, a distinction is normally made between a warning or informing mode in which the driver is provided with information or instructions; an assisting mode in which temporary control is automatically initiated but can be overruled by the driver, and an automatic mode where driving decisions and actions are fully carried out by the system (e.g. Rothengatter et al, 1995; Marchau & Hoedemaker, 1995). Hence, the values concerned to be relevant for automation are: (1) information; (2) assistance, and (3) automated.
- An *instrumentation* dimension, representing the distribution of technology between vehicle and road infrastructure. As mentioned in the previous section, this distribution can vary from concepts in which all the technology is put in the vehicles up to concepts in which all devices are part of the roadway. The values considered are: (1) in-vehicle; (2) both vehicle and infrastructure, and (3) infrastructure.
- A *user* dimension, representing the scale of application of AVG technology within traffic. The AVG technology could initially be developed (for a long time) for specific groups based on their e.g. homogeneous movement characteristics (e.g. travel motive) or preferences (e.g. travel comfort, traffic safety, etc.). The values considered are: (1) target groups, and (2) all users.
- A *road network* dimension, representing the kind of roads for which AVG concepts could become available. Automated traffic could be separated from manual-driven vehicles, using dedicated lanes. Highly synchronised systems, for instance, would encompass traffic flow control strategies such as platooning. Another option is to mix automated and non-automated driving. Considering the different degrees of density of

a spatial network we distinguish the values: (1) dedicated lanes; (2) motorways, and (3) all roads.

The set of possible AVG concepts can now be defined as the set of all possible combinations of values of underlying dimensions. There are $3^4 \times 2 = 162$ of such combinations. Table 3-1 summarises the specified dimensions and their selected values. In theory, each combination could be regarded as an alternative. However "the design or implementation or both, of many of these combinations is either highly unlikely or nearly impossible" (Stevens, 1994: p. 43). In the next section, unlikely and/or impossible combinations will be eliminated.

Table 3-1: Dimensions and values of AVG concepts

dimension	values		
	(1)	(2)	(3)
function	longitudinal	lateral	longitudinal & lateral
automation	information	assistance	automated
instrumentation	vehicle	vehicle/infrastructure	infrastructure
users	target groups	all users	
roads	dedicated lanes	motorways	all roads

3.4 A scan of theoretical AVG concepts

Of course, an in-depth study of each of the 216 AVG concepts would not be manageable in developing a robust policy framework. There is a need to reduce this set. Eliminating those concepts, which are unlikely and/or impossible to implement, can be helpful in the required reduction problem. Of course, the criteria unlikeliness and impossibility should be further operationalised in the elimination process. These notions primarily refer to the potential contribution of the AVG concept to general transportation goals, i.e. accessibility, safety, and environmental sustainability (Ministry of Transport, Water Management and Public Works, 1990; Van der Heijden et al, 1995) and/or to the technical and societal feasibility of implementing an AVG concept on a large scale within the time horizon of this study. The concepts, which do not meet at least one of these criteria, or the concepts for which this is highly uncertain, are labelled implausible. The result of this elimination process is defined as a set of plausible AVG concepts.

The first focus is on elimination by screening. Due to the systematic derivation of AVG concepts from basic dimensions, it is assumed that an AVG concept is implausible in case one of the combinations of levels of constituting dimensions is implausible. The implausibility of a partial combination is judged on the basis of expert knowledge expressed in literature. This simplifies the screening considerably, because now the first step is to analyse a limited set of pairs of values. The number of different pairs of values which can be derived from two dimensions with each three values is $3 \times 3 = 9$; for dimensions with two respectively three values, the number of possible pairs is $2 \times 3 = 6$. Hence, for the

defined dimensions and values, the number of pairs is $(9+9+6+9) + (9+6+9) + (6+9) + (6) = 88$. Furthermore, each implausible pair reduces the amount of possible AVG concepts substantially.

In Figure 3-2 an overview of plausible and implausible pairs is given. Scanning the implausibility of, for instance, the first pair in Figure 3-2 (information on longitudinal control in the vehicle) implies that primarily the contribution of this pair to the transportation goals mentioned is evaluated and, secondly, the technical and societal feasibility of this pair.

A '0' refers to an implausible combination and a '1' to a plausible combination. Those pairs that cannot be judged with respect to the criteria as mentioned above are logically valued '1'. Since our objective is to eliminate implausible combinations, only an explanation of the number of pairs valued '0' in table is given:

function - automation (f - a): The implementation of AVG concepts only fully automating longitudinal support or lateral support, is highly unlikely. This would mean that all longitudinal or lateral driving actions are fully automated whereas the lateral respectively the longitudinal actions are executed manually by the driver. This could give serious conflicts in driving situations like e.g. lane changing, which requires integration of longitudinal and lateral actions. Therefore, the combinations of f1 and f2 with a3 are considered '0'.

function - instrumentation (f - i): Longitudinal support and lateral support are generally expected to be initially based on in-vehicle devices only. "At first there will be equipped vehicles in an unequipped environment and vice versa" (Zimmer et al, 1994: p.170). For lateral support, some infrastructure instrumentation is needed to handle lane keeping properly. However, also in the longer run, longitudinal or lateral support by roadway instrumentation only is unlikely; i.e. f1 and f2 in combination with i3 are valued '0'.

automation - instrumentation (a - i): The distribution of technology between vehicle and road infrastructure and the degree of automation are strongly related. An infrastructure equipped with some intelligence could be an interesting option in this context. For instance, the maximum speed of vehicles could be influenced on parts of the network, depending on state of traffic, environment, etc. Nowadays in the Netherlands, there is increasing attention for Intelligent Speed Adaptation (ISA). These systems warn or intervene the driver in case of exceeding the speed limit within local traffic areas. These systems have high potential regarding the contribution to traffic safety (e.g. De Visser et al, 1999). However, some vehicle instrumentation is needed to enable these systems to operate properly. Furthermore, the technical feasibility of intervening systems based on infrastructure instrumentation only, is very uncertain in terms of control of each equipped vehicle. Especially the continuous anticipation on manoeuvres of unequipped vehicles by infrastructure intelligence is extremely complex from a technical point of view. This requires at least separate lanes. In summary, informing and assisting AVG based on infrastructure

Figure 3-2: Plausible and implausible combinations of characteristics of AVG concepts

dimensions	values	f1: longitudinal	f2: lateral	f3: long+lat.	a1: information	a2: assistance	a3: automated	i1: vehicle	i2: veh/infra	i3: infra	u1: target groups	u2: all users	r1: ded. lanes	r2: motorways	r3: all roads
f: function	f1: longitudinal				1*	1	0	1	1	0	1	1	1	1	1
	f2: lateral				1	1	0	1	1	0	1	1	1	1	1
	f3: long. & lat.				1	1	1	1	1	1	1	1	1	1	1
a: automation	a1: information							1	1	0	1	1	0	1	1
	a2: assistance							1	1	0	1	0	1	1	1
	a3: automated							0	1	1	1	0	1	1	0
i: instrumentation	i1: vehicle										1	1	1	1	1
	i2: veh/infra										1	1	1	1	0
	i3: infra										1	1	1	1	0
u: users	u1: target groups												1	1	1
	u2: all users												0	1	1

* a '1' refers to plausible combinations and a '0' refers to implausible combinations

instrumentation only, seems highly unlikely, i.e. a1 and a2 in combination with t3 are valued '0'.

Fully automated driving with the technology totally placed in the vehicle minimises the dependence on infrastructure adaptations. This seems a logical path, knowing that these adaptations develop gradually (Catling, 1994). Research, however, points out that some infrastructure electronics will be necessary to enable fully automated driving, for instance to handle different weather conditions (Stevens et al, 1995) or lane keeping. Full automation by means of in-vehicle technology only, is consequently valued '0'.

automation – users (a - u): Assisting and automated support for all users will perhaps become reality in the distant future but is beyond the time horizon of this study. Assisting support for everybody is not to be expected before 2030 (Underwood, 1992), and automated traffic for target groups not before 25 to 50 years from now (e.g. Godthelp & Jansen, 1993; Diebold Institute, 1995; Verweij, 1995). Assisting and automated support for everybody are valued '0'.

automation – roads (a - r): Development of full automation of driving tasks has been focusing on motorways and dedicated lanes. For lower road levels this is, technically, still too complex as one has to deal with a variety of traffic and roads. Automated driving on all roads is valued '0'. In case of full automation, many authors argue that automated and non automated vehicles should be separated to minimise negative impacts on safety, capacity, driver acceptance, etc. (e.g. Tsao et al, 1993). Others argue that one should try to achieve

automated driving within mixed situations, as dedicated lanes will only be constructed if there are sufficient vehicles that will use these lanes (e.g. Ward, 1997). The construction of dedicated lanes for informing driver support seems unlikely, since it does not make sense to construct dedicated infrastructure while leaving the decision freedom up to the drivers and thus not knowing what the benefits will be; hence, informing support on dedicated lanes is valued '0'.

instrumentation – roads (i – r): The adaptation of infrastructure will be restricted to certain parts of the traffic network, namely those parts where the adaptations are efficient and effective. It is highly unlikely that all the roads will be equipped with intelligence in the next decades. This should require huge investments and an enormous organisation at national level, which seems highly unlikely from a cost-benefit perspective. Here the appropriate role of the public sector should be to invest when public benefits are greater than implementation costs (Kanninen, 1996). As such, the partial or total adaptation of all roads with instrumentation is valued '0'.

users – roads (u – r): From our definitions on users and roads it is not logical to assume dedicated lanes for everybody. Hence, dedicated lanes for everybody is valued '0'.

By eliminating those AVG concepts that comprehend one of the implausible pairs, a number of 37 plausible AVG concepts result. These are fully described in Table 3-2. This set is still too large to allow in-depth research for each separate concept. Hence, there is a need to further reduce this set to smaller, manageable proportions. Such reduction could be achieved by finding out:

1. whether combinations of three or more values of underlying AVG concept-dimensions are implausible;
2. whether different AVG concepts could be combined into one, more basic AVG concept which evolves over time.

The first approach for further elimination of AVG concepts is based on the elimination of the implausible combinations of three or more values of the underlying dimensions. For instance, the combination of automated driving on all motorways by intelligence in the infrastructure (AVG concept 37) could be questioned. Current research moves away from this option due to enormous uncertainties about technical feasibility and cost-benefit ratio of the huge required adaptations of infrastructure. For the time being, however, we will not eliminate this combination. As yet, none of the other concepts seem fully implausible either.

The second approach refers to the fact that some concepts could occur at the same time, whereas others are logically expected to follow each other. For instance, all drivers could get informed on longitudinal driving tasks on all roads, whereas some target groups are assisted on motorways only, i.e. AVG concept 4 could be combined with AVG concept 8.

Table 3-2: Plausible AVG concepts

AVG concept	function	automation	instrumentation	users	roads
1	longitudinal	information	vehicle	target groups	motorways
2	longitudinal	information	vehicle	target groups	all roads
3	longitudinal	information	vehicle	all users	motorways
4	longitudinal	information	vehicle	all users	all roads
5	longitudinal	information	vehicle/infra	target groups	motorways
6	longitudinal	information	vehicle/infra	all users	motorways
7	longitudinal	assistance	vehicle	target groups	ded. lanes
8	longitudinal	assistance	vehicle	target groups	motorways
9	longitudinal	assistance	vehicle	target groups	all roads
10	longitudinal	assistance	vehicle/infra	target groups	ded. lanes
11	longitudinal	assistance	vehicle/infra	target groups	motorways
12	lateral	information	vehicle	target groups	motorways
13	lateral	information	vehicle	target groups	all roads
14	lateral	information	vehicle	all users	motorways
15	lateral	information	vehicle	all users	all roads
16	lateral	information	vehicle/infra	target groups	motorways
17	lateral	information	vehicle/infra	all users	motorways
18	lateral	assistance	vehicle	target groups	ded. lanes
19	lateral	assistance	vehicle	target groups	motorways
20	lateral	assistance	vehicle	target groups	all roads
21	lateral	assistance	vehicle/infra	target groups	ded. lanes
22	lateral	assistance	vehicle/infra	target groups	motorways
23	long. & lat.	information	vehicle	target groups	motorways
24	long. & lat.	information	vehicle	target groups	all roads
25	long. & lat.	information	vehicle	all users	motorways
26	long. & lat.	information	vehicle	all users	all roads
27	long. & lat.	information	vehicle/infra	target groups	motorways
28	long. & lat.	information	vehicle/infra	all users	motorways
29	long. & lat.	assistance	vehicle	target groups	ded. lanes
30	long. & lat.	assistance	vehicle	target groups	motorways
31	long. & lat.	assistance	vehicle	target groups	all roads
32	long. & lat.	assistance	vehicle/infra	target groups	ded. lanes
33	long. & lat.	assistance	vehicle/infra	target groups	motorways
34	long. & lat.	automatic	vehicle/infra	target groups	ded. lanes
35	long. & lat.	automatic	vehicle/infra	target groups	motorways
36	long. & lat.	automatic	infrastructure	target groups	ded. lanes
37	long. & lat.	automatic	infrastructure	target groups	motorways

An example of concepts, which might be implemented in succession, is presented by the AVG concepts 18, 19 and 20. Drivers may, initially, be assisted on lateral driving tasks on dedicated lanes only and later on, as the in-vehicle technology progresses, this might be extended to other types of roads. As such, the AVG concepts 18, 19 and 20 can be

interpreted as one basic concept, which evolves in time in terms of increased road network applicability. Hence, in order to further analyse and reduce the plausible concepts, insight is needed into the temporal dimension of AVG developments. In terms of the specified dimensions and selected values of AVG concepts, the question is whether we may assume that some AVG concept values are likely to succeed each other or not. In the following section the general expectations regarding the implementation process of AVG concepts will be presented.

3.5 The temporal dimension of AVG developments

Throughout the years possible futures of AVG have been hypothesised by different authors. For instance, Godthelp & Jansen (1993) consider five stages along which AVG could develop, starting at today's motorway system:

1. introduction of separate systems, supporting longitudinal car following and collision avoidance;
2. introduction of integrated longitudinal support systems;
3. extension of integrated systems with lateral support components;
4. introduction of dedicated lanes for longitudinal and lateral fully automated vehicles;
5. extension of dedicated lanes for all major connections.

Timescales for phased introduction differ from 25 to 50 years from now before stage 5 is reached. Also more detailed outlooks have been given since.

Stevens (1997) hypothesises increasing levels of vehicle control in terms of the levels: 'partial vehicle control', 'early vehicle highway automation' and an 'automated highway system'. Each level is further operationalised in terms of the basic systems relevant to AHS (Table 3-3). Warning devices for separate driving tasks are likely to come first, followed by some limited assistance. Next, support for more driving tasks is expected. Dedicated lanes are expected to be introduced for high levels of automated driving only as the benefits in this stage would outweigh the cost of road construction.

Ward (1997) hypothesises a similar development as Stevens, with one specific exception. The construction of dedicated lanes should be avoided in his opinion, as this is a major obstacle to further developments. This notion refers to the 'chicken-and-egg' problem: policy makers will only construct specific lanes if there are enough equipped vehicles that will use these lanes and vehicle manufacturers will only produce equipped vehicles if there are enough lanes to use them. Therefore, one should aim at a development towards fully automated driving, which allows a mix of both manual and automated driving and avoids dependence on dedicated lanes and complex entry/exit procedures.

Table 3-3: Potential levels of vehicle control related to AHS

SENSING	longitudinal sensing		lateral sensing		road conditions	veh./driver condition
	throttle	throttle & brake	warning	steering	set speed & spacing	check-in & check-out
PARTIAL VEHICLE CONTROL (driver transfers control to/from system):						
ACC. collision warning	X*	-	-	-	driver	no
ACC. collision avoidance	-	X	-	-	driver	no
Lane departure warning	-	-	X	-	driver	no
Lane keeping actively	-	-	-	X	driver	no
ACC lateral & long. warning	X	-	X	-	driver	no
EARLY VEHICLE-HIGHWAY AUTOMATION (driver transfers control):						
Not dedicated	-	X	-	X	driver	no
Dedicated lane	-	X	-	X	system	warning if failed
AUTOMATED HIGHWAY SYSTEM (system assumes and returns control):						
	-	X	-	X	system	yes

* A 'X', respectively '-' refers to whether a system has, respectively has not, the indicated sensing and controlling characteristics (source: Stevens 1997)

Benouar et al (1998) propose the following six market packages, which may be interpreted as incremental automation steps towards automated driving:

1. Automatic Speed Reduction at Curves and Unsafe Headway
2. Automatic Return to Lane with Driver Override
3. Vehicle-To-Vehicle Communication for Brake Control
4. Adaptive Cruise Control (ACC), Vision-based Lane Keeping, Driver Monitoring
5. ACC or Vision-based Lane Keeping
6. ACC and Vision-based Lane Keeping at Low Speeds.

These packages are highly flexible in their use, as they initially require none or a minimum of infrastructure modifications. They can be used on motorways with or without dedicated lanes as well as on lower level roads, like urban roads.

Tsao (1995) describes a different development of an Automated Highway System for urban areas. The first stage starts directly with advanced forms of automated lane cruising of vans and mini-buses providing freeway shuttle services on High Occupancy Vehicle (HOV) lanes. Automated lane cruising include basic functions such as automated lane keeping, automated vehicle-following and safe speed determination. The professional driver supervises the performance of the vehicle driving task. Next, HOV lanes are constructed and modified at network level for automobile automation. Automobile owners can use automation features throughout their freeway trip. In the following stages the infrastructure is further improved to allow for extended vehicle control such as lane changing and platooning.

Summarising, there are different views in literature on future AVG developments. Most researchers argue a gradual change of the present car system, based on incremental absorption and slowly intensifying use of new technologies (Van Arem, 1996; Hall, 1997). In this context the term evolutionary development is often used. These researchers postulate that evolutionary planning of AVG implementation is most suitable, starting with a transport system without any automated devices up to a transport system which incorporates fully automated lanes. This evolutionary planning is based on different reasons, including (Stevens, 1997):

- acceptance could grow: drivers could become accustomed to warning devices before systems are introduced which control a driving task; experience could first be gained with systems which support one specific driving task and next with integrated systems which support a combination of driving tasks. As such, the acceptance of the partial automation of vehicle driving could grow before the introduction of fully automated driving;
- technology could be developed: system designers could further work out the details of transferring control between driver and technology;
- vehicles could be developed: vehicle designers could develop vehicles being more suitable for fully automated driving, because many of the vehicle features required by partial automation might also be required for fully automated driving and as such might be upgraded to enable support of today's vehicles.

On the other hand, the plausibility of a more revolutionary introduction of AVG concepts has been considered, starting with the implementation of advanced automated AVG concepts on dedicated lanes and for target groups. Within time these concepts could penetrate into other user groups and could expand over the road network. The reasons for these more radical replacements of transport facilities in particular are:

- a clear superiority of the new technology over old technology: AVG concepts which fully take over the vehicle driving task have the highest potential regarding the improvement of traffic performance as compared to AVG concepts which only support part of the vehicle driving task;
- technology design might be less complex: the application of separate AVG concepts, each automating some part of the vehicle driving task, could interfere. In case of full automation of the total vehicle driving task, this problem is avoided;
- acceptance could grow: fully automated AVG concepts could have a 'boutique' function to potential users (Del Castillo et al, 1997). New user groups could be attracted to make use of these facilities, because of the substantial improvements of vehicle driving performance given by these concepts.

Although the evolutionary and the revolutionary view on future AVG developments might look completely different at first sight, they match to some extent when analysing each

perspective in terms of the separate dimensions and values as defined in our study. Both views imply that some of the AVG concept dimensions will develop in a similar way. This concerns the dimensions instrumentation, users and roads. Each of these dimensions are more or less expected to develop in an evolutionary way. As to the other dimensions (function and automation) the nature of future developments is not so obvious. As yet, both evolutionary and revolutionary AVG developments seem to be possible with respect to these dimensions.

According to this view, the resulting AVG concepts of our quick scan, as presented in Table 3-2, can now be reduced further into different groups of evolving AVG concepts. By assuming that the dimensions instrumentation, users and roads will develop in an evolutionary way, these groups of evolving concepts are formed based on an equal type of functionality as well as automation level. In particular, seven groups of AVG concepts, which comprehend those plausible concepts that are likely to evolve from each other, can be identified. For instance, the first evolving AVG concept covers the plausible AVG concepts 1 to 6, the second group covers the AVG concepts 7 to 11, up to the seventh group which covers the AVG concepts 34 to 37 (see Table 3-4). These evolving, plausible AVG concepts will be studied in-depth in the following chapters.

Table 3-4: Plausible, evolving AVG concepts

AVG concept	revolutionary/evolutionary dimensions		evolutionary dimensions		
	function	automation	instrumentation	users	roads
1	longitudinal	information	- vehicle - vehicle/infra	- target groups - all users	- motorways - all roads
2	longitudinal	assistance	- vehicle - vehicle/infra	- target groups	- ded. lanes - motorways - all roads
3	lateral	information	- vehicle - vehicle/infra	- target groups - all users	- motorways - all roads
4	lateral	assistance	- vehicle - vehicle/infra	- target groups	- ded. lanes - motorways - all roads
5	long. & lat.	information	- vehicle - vehicle/infra	- target groups - all users	- motorways - all roads
6	long. & lat.	assistance	- vehicle - vehicle/infra	- target groups	- ded. lanes - motorways - all roads
7	long. & lat.	automatic	- vehicle/infra - infra	- target groups	- ded. lanes - motorways

3.6 Conclusions and discussion

The main purpose of this chapter is structuring and limiting the scope towards plausible AVG concepts for implementation from the view of public policy making. Overall, the analysis performed in this chapter implies that it is possible to limit the set of future possible AVG concepts to manageable proportions, which enable further, in-depth research.

In this chapter an identification, specification and initial reduction of possible AVG concepts has been made using morphological analysis. The basic dimensions of AVG concepts regarding AVG implementation have been identified and the values of these dimensions have been specified. It appears that the number of theoretical, possible combinations of values, and as such the number of AVG concepts, is considerable. However, a first analysis points out that several AVG concepts are implausible and a considerable reduction can be made towards plausible configurations. Furthermore, some plausible AVG concepts are likely to be implemented in succession as for other concepts this not so certain. By applying this temporal dimension, seven plausible, evolving AVG concepts can be defined, based on different functionalities and different levels of automation. Basically, the future implementation of these concepts depends upon the assumption one has on the nature of future AVG developments. Assuming, for instance, that the implementation of these concepts will follow, to some degree, an evolutionary pattern the results of this study can be interpreted as follows.

First, it is most likely that there will be informing and assisting intelligence in vehicles, either for longitudinal or lateral support, functioning in a mixed situation with conventional vehicles and first applicable on motorways only and later on also on the underlying road network. Initially, the industry will be the driving force in this phase, claiming gains in individual traffic safety and driving comfort. Public authorities could accelerate the rate of penetration by flanking policy measures like subsidising purchase and/or use of the technology. Increased penetration could improve traffic safety and efficiency. Next, dedicated lanes could be constructed on (initially major) motorways for specific groups, enabling improved performance of assisting concepts for both longitudinal and lateral support, followed by the implementation of automated intelligence. These latter concepts require a minimum of scarce road space and claim a maximum of gains in traffic capacity and traffic safety. Here a close, active cooperation between public infrastructure planners and private vehicle technology producers is inevitable and absolutely essential.

On the other hand, if a more revolutionary development is assumed, the development could start with the implementation of automated devices in vehicles and infrastructure, for both longitudinal and lateral support, functioning on dedicated lanes for target groups only. Next to manufacturers, public policy makers will play an important role in this phase, as they are road operators/owners and as such first responsible. The implementation of automated concepts on dedicated lanes should improve traffic flow efficiency and trip reliability not only on these lanes, but also to some degree on non-automated lanes. In time, more lanes could be instrumented with intelligence, encouraging other user groups to make use of automated facilities during their trips. Furthermore, some AVG functionalities might

become of use on roads, which are not instrumented, informing or assisting drivers on specific sub-tasks.

Of course our choices (of dimensions and values in terms of mutual independence and completeness) and arguments (for eliminating combinations and assuming evolutionary or revolutionary developments) are (and should be) subject of discussion. These choices and arguments mark the start of a systematic attempt to make the uncertainty in this field more transparent by structuring the subject of AVG implementation, enlightening basic conditions and by providing stricter functional requirements. Evidently, they should and will be further elaborated and improved in the following chapters.

As stated in section 2.4, the next step involves a more in-depth analysis of these plausible AVG concepts, in relation to the basic conditions postulated for each of the concepts. This implies identifying and evaluating the initial market characteristics of the different AVG concepts and the barriers, which might obstruct market introduction and/or further deployment. The first question here is how to perform such an analysis. This question will be dealt with in the next chapter.

Chapter 4.

Evaluating plausible AVG concepts: a Delphi approach

4.1 Introduction

In the previous chapter the variety of possible AVG concepts has been structured and reduced by the elimination of those concepts which are unlikely to contribute to general transport goals and/or are infeasible from a technical or societal point of view. The next step involves an in-depth analysis of the plausibility of the remaining AVG concepts. In this chapter the set-up of a study is specified to perform such an analysis.

In chapter 2 it was argued that the expertise and insights of experts are needed for this type of analysis, as empirical data is lacking and extrapolation from past observations would be an invalid approach. Hence, in section 4.2, different ways to systematically collect expert opinions are considered. Moreover, experiences from similar studies are presented. The Delphi technique is considered most appropriate to identify and evaluate the conditions for the implementation of AVG concepts. The Delphi technique is further discussed in detail in section 4.3. The set-up of the Delphi study as part of this thesis is presented in section 4.4. and section 4.5. The chapter ends with some conclusions.

4.2 Expert opinion techniques used and experience gained in related studies

For decades expert judgements have been used to support decision making and make predictions about the future within several problem areas (Gupta & Clarke, 1996). In particular, for those problems for which empirical data is not available and extrapolation from past observations is insufficient for valid forecasts, the expertise and insights of experts are considered to be of potential utility (Helmer, 1988).

There are different techniques to gather expert opinions. For instance, one can interview an expert individually. This can be done face-to-face, by telephone, by mail, etc. Face-to-face techniques enable the interviewer to assess the expertise of the expert personally. However, one often is interested in the opinion of more than one expert for different reasons, including (Lock, 1987):

- *bias*: individuals come to judgements based on their specific point of view, particular expertise, personal preferences, etc. By using groups of experts, one is likely to cancel out these limitations and provide more valid judgements as compared to judgements based on an individual opinion;
- *accuracy*: by interrogating only one expert, no information is obtained with regard to the accuracy of judgements made. If the opinions of a group of experts have been collected, it is often possible to determine the accuracy of the judgements made. For instance, in case different experts have been invited to estimate the moment that a technology will be introduced, using for instance single point estimates, the accuracy of judgements of the estimations given can be judged, in terms of deviations from the average group opinion.

In general, it is typically assumed that 'more heads know more than one' when consulting a group of experts. After all, a group of experts will have at least the same amount of knowledge as their least knowledgeable member (Rowe, 1998).

In practice, it is usually difficult to meet each member of a group of experts individually, as they might be distributed all over the world. Another option is to collect the group of experts at a single place at a single time. However, as experts are busy people it is often difficult to organise such a meeting from a logistical point of view. Furthermore, in such meetings communication among experts is generally stimulated. This has the advantage that divergent individual opinions, due to, for instance, misunderstandings, different perceptions, divergent knowledge etc., can be discussed straightaway. On the other hand, enabling communication between participating experts could also have some negative effects.

For instance, some individuals might dominate other members of the group because of their professional position or vocal capabilities. Others might be less communicative or reserved within group settings, in particular when their individual opinion is extreme as compared to the general opinion.

An alternative for individual interviews or group discussions is performing a survey among experts. Surveying is the most common method to get input from a group of experts, when face-to-face meetings are impractical (Porter et al, 1991). The Delphi technique concerns a specific way of surveying. It is a survey technique by which respondents are repeatedly and independently interrogated, usually by means of questionnaires, about issues under study, aiming at consensus within the response group. In order to reach consensus, responses to the initial questionnaire are summarised and returned to the respondents. Respondents are now asked to confirm or revise their opinion, given the group opinion. The level of consensus as desired by the researcher mostly determines the number of interrogation rounds. The group opinion is then formed by the opinion in this latter round.

The Delphi technique has often been used in practice as it has a.o. proven its forecasting capabilities and can be applied straightforward to several fields of interest (Parenté & Anderson-Parenté, 1987). Also in the field of transport telematics different studies have been performed to identify and assess future developments by using the Delphi technique. We will briefly discuss some of these studies.

For instance, Sviden (1988) identifies a likely scenario of transport telematics developments for the European market using the Delphi technique. The scenario is given in terms of the states of transport telematics for the years 1990, 1995, 2000, 2010, 2020 and 2040, so called scenes. These scenes consider the state of traffic, the use of different telematics systems, the impacts of implementation as well as some policy problems for implementation. Expert opinions have been used to estimate several events for each scene. For instance, in Table 4-1 the expected market penetration of some AVG systems is presented. It is expected that the implementation of the different systems will follow an evolutionary pattern. Experts considered highly improved traffic performance the main impact of implementation; costs are assumed to be the main barrier.

In this study the knowledge of experts has been used as the input for the design of a scenario on how transport telematics might reshape future road traffic. The Delphi technique was chosen because of its structuring ability of communication needed for this type of exploratory research and its typical feedback properties over different interrogation rounds. Furthermore, the first interrogation round was used to form a first idea on how future transport telematics scenes might look. The number of interrogation rounds was put at two, as there were limited resources to conduct more rounds.

Table 4-1: Time estimates of EU market penetration of some AVG systems

systems	speed headway keeping	collision avoidance & lane keeping	automated highway
diffusion degree			
successful lab tests	1990	1995	2000
system introduction	2000	2000	2010
majority use by commercial vehicles	2010	2010	2025
majority use by all automobiles	2020	2030	2045
mandatory use by all road vehicles	2050	2065	-

Source: Sviden (1988)

Underwood (1990, 1992) also used the Delphi technique in two similar studies, in order to explore the likely development of a range of transport telematics systems as well as related influencing factors. Both studies focused on so-called 'intelligent vehicle highway systems' for North America and were conducted in 1987 and 1991 respectively.

The first study focused on qualitative factors and general projections of selected systems. In particular, the driving forces as well as barriers to implementation, policy initiatives and impacts were assessed. The argument for choosing the Delphi technique in this study was that this technique is "... often used for forecasting the development of new technologies and policy events that can not be effectively modelled by trend extrapolation..."(Underwood, 1990: p. 59). Furthermore, the study aimed at reaching a certain level of consensus among the respondents. After three interrogation rounds the desired level of consensus was reached and the results of the third round were presented as the final group opinion. Basic traffic problems, i.e. congestion and safety, as well as improved driving convenience are expected to be the driving forces for future AVG implementation on North American motorways. The technological reliability of systems, liability and consumer acceptance are considered major barriers to implementation. Policy initiatives which establish standards, protect liability, finance R&D and equip roadways (only for automated motorways), are recommended.

The second study of Underwood (1992) focused on quantitative estimates of market penetration and user costs of several telematics systems. Again, the desire for consensus among experts was a major reason to choose the Delphi technique. In the second Delphi study only two interrogation rounds were needed to reach the desired level of consensus. The results being relevant to AVG systems are presented in Table 4-2. Again, an evolutionary pattern is expected for the implementation of AVG systems. Regarding automated highways there was a great deal of disagreement among the respondents. It was argued that these would never be implemented without governmental support and if they were adopted, they would only be of use for a small part of the traffic population.

Table 4-2: Time and cost estimates of US market penetration for some AVG systems

systems	speed headway keeping	front obstacle coll. avoidance	lane keeping	automated highway
market characteristics				
diffusion degree:				
introduction	1995	1998	2000	2030
5% diffusion	2004	2008	2011	2040
50% diffusion	2015	2020	2032	never
mandatory	2050	2030	2050	never
user costs at 5% penetration	\$400	\$750	\$800	-

Source: Underwood (1992)

A last study, relevant in this context, researches interurban transport telematics systems for European motorways that are likely to become available in the next 5 to 10 years (McDonald et al, 1997). Besides traffic management systems (e.g. ramp metering,

automatic incident detection), some AVG systems are considered, including in-vehicle collision avoidance systems and fully cooperative systems (e.g. automated motorways). Also in this study, experts' opinions were collected using the Delphi technique; in order to elicit the likeliness of implementation of systems on 75% of the interurban motorways, both for the year 2000 and 2010. Furthermore, factors were assessed which might delay implementation. As in the above-described studies, AVG implementation is expected to develop in an evolutionary way, although in this study it was argued that fully automated driving on motorways might never be introduced as many of its characteristics can be achieved with in-vehicle systems. The major barriers to implementation involve availability for further funding, overall purchase/implementation cost, government policy and the overall cost-benefit ratio.

In this study, the Delphi technique was favoured as a method that might be used for determining the most likely scenarios for short-term and medium-term periods as expected by decision-making experts. Furthermore, in this study the answering to questions using the Delphi technique required a minimum of time. Hence, the response frequency was increased. Finally, the iterative nature of the Delphi technique allowed fine-tuning the response group, in terms of forming specialised subgroups of respondents which are assumed to be more appropriate to deal with specific questions.

Also, studies have been performed which focus on the development of transport telematics for urban areas (e.g. Scapolo, 1996). Scapolo concludes the level of available investments, lack of harmonisation and standards, legal issues and public acceptance to be the major constraints for implementation. The choice of using the Delphi technique was motivated by using similar reasons as indicated in the other studies described above. In this context no studies have been found which made use of other techniques.

In summary, a considerable effort has been made to research conditions regarding future implementation of transport telematics. Characteristics of future markets have been estimated and general impediments to implementation have been identified. Although the results of these studies are helpful, they are, for different reasons, not sufficient for our research. These studies consider transport telematics in general; as such, no in-depth information is obtained with regard to future conditions of AVG implementation in particular. Furthermore, the focus in these studies is on implementation regarding Europe or North America. Therefore, only experts within these continents have been consulted. As AVG research and developments take place within Europe, the US and Japan, some knowledge (for instance on technical feasibility) might not be included. Next, there is a strong focus on conditions for implementation of AVG on motorways only. In our research we are also interested in the conditions for the implementation of AVG concepts at lower road levels.

Methodologically, it appears that the Delphi technique is highly in favour to collect and synthesise expert opinions regarding future transport technology developments. The reason for choosing the Delphi technique in these studies is motivated by different reasons including: (a) the fact that the Delphi technique is appropriate for researching those technology developments for which traditional extrapolation techniques are not effective;

(b) the Delphi technique has proven to give valuable results when limited resources for research are available, and (c) the technique can be applied rather straightforward as compared to other expert opinion techniques. It further appears that the results of the different studies described above are rather consistent. The results show similar time patterns of future implementation and the conditions for implementation also correspond to a large degree.

Therefore, in this thesis the Delphi technique is also chosen to identify and assess the conditions of future AVG implementation. In the following section we will further elaborate on the methodological characteristics of the Delphi technique.

4.3 The Delphi technique

The Delphi technique was originally developed for military applications at the RAND Corporation by Olaf Helmer and Norman Dalkey in the early 1950s. Next, the Delphi technique became recognised as a useful method for technology forecasting by the American business and industry. Since then, the Delphi technique has been applied within different problem domains (for a comprehensive overview of Delphi applications between 1975 and 1994, see Gupta & Clarke, 1996).

In general, a Delphi study consists, by means of questionnaires, of a series of repeated interrogations or rounds of a group of individuals whose opinions or judgements are of interest. After the initial interrogation of each individual, each subsequent interrogation is accompanied by information about the preceding round of responses, usually presented anonymously. The individuals are thus encouraged to reconsider and, if appropriate, to change their earlier response in the light of replies of other members of the group. The main goal of the Delphi procedure is to reach consensus among a number of experts regarding the issue under investigation (Sackman, 1975). As soon as a desired level of consensus has been reached, the final group position is determined by calculating the average.

The Delphi technique is used to facilitate communication on a specific task. The technique involves anonymity of responses, iteration, controlled feedback to the participants and statistical group response (e.g. Rowe et al, 1991):

- *anonymity*: participants are approached by paper and mail and act anonymously, as social interaction among participants could negatively influence the individual opinion. Anonymity should enable participants to judge the subject of interest on its merits only, without possible dominance of some experts or group conflicts. It should provide more accurate judgements than those produced by techniques which involve interacting individuals;
- *iteration*: the Delphi method consists of a number of repeated interrogations or rounds. After each round participants are allowed to modify an earlier reply. The number of repeated interrogations usually depends on the degree of consensus defined by the Delphi organisers;

- *controlled feedback*: after each round participants are confronted with both the group opinion and their individual opinion. Participants are hereby encouraged to evaluate their earlier replies with respect to the group opinion. The intermediate group response is often represented by some descriptive statistics (frequencies, median, mean, variance, etc.), although arguments underlying individual opinions can also be included;
- *statistical group response*: after the final round the group opinion is represented by an adequate measure for the central tendency of opinions. Often, the dispersion of opinions is given as well, as this indicates the degree of consensus among the experts.

There are different variants of Delphi studies, related to the purpose they serve. They can, for instance, aim at (Mulder et al, 1996):

1. forecasting future developments within a certain problem area;
2. identifying and exploring possible, future alternatives for a problem area, and
3. structuring the problem area in order to create the common ground to develop common programmes.

In this study the Delphi technique is used to identify and assess the conditions of future AVG implementation. Hence, the forecasting function of the Delphi technique is necessarily limited.

Throughout the years, several variants of the traditional Delphi technique have been developed and applied in order to improve the quality of the results by using, for instance, partial anonymity, a different number of iterative question rounds (ranging from two to ten), controlled feedback of opinions of specific groups within the panel (specialists versus generalists), statistical group responses varying from one single number to complete distributions of opinions, weighing opinions according to the degree of expertise, etc.

The strength of the Delphi method is its ability to explore, coolly and objectively, issues that require personal judgement (Gordon, 1994). Here the assurance of the participant's anonymity, controlled feedback and iteration and a statistical group response should result in reliable conclusions. The Delphi technique should provide more accurate judgements than those techniques which might be attained by interacting groups or by individuals (Rowe et al, 1991) There are, however, some important points for attention, which should be taken into account when setting up and executing a Delphi study:

- The selection of experts should be handled with care. Given the objectives of the study, the variety of expertise pursued should be made explicit. The selection of non-experts could give a "garbage in garbage out" effect (Webler et al, 1991).
- Experts usually are extremely busy people. Consequently, the possibility and willingness of experts to participate in a Delphi study is often a problem together with the possibly increasing drop-out rate over subsequent question rounds (Jillson, 1975).

- The Delphi organisers deal with the interpretation of responses, intermediate feedback, and final results. All responses are thus subjectively filtered through by the Delphi organisers before being seen by anyone else (Sackman, 1975).
- The reliability and accuracy of the results should not be overestimated (Woudenberg, 1991). The results are based on opinions with regard to future developments, to a high degree assuming a lack of surprises. Almost by definition we know that this assumption is not valid.
- Finally, the frequently used stopping criterion for the number of interrogation rounds in Delphi studies (a predefined level of consensus within the group) is arbitrary (Maasen & Van Vught, 1984). This measure does not give any information on the consistency of the individual answers over different rounds. Hence, at group level consensus might appear after a few interrogation rounds, whereas individual participants have given significantly different answers between subsequent rounds. As such some 'false consensus' might exist within the group.

With respect to reliability and accuracy, it should be noted that these notions primarily refer to the forecasting function of the Delphi technique. We already stated that, in this study, the Delphi method is used to analyse the plausibility of future AVG concepts in-depth. In particular, the study aims at identifying and estimating the conditions of future implementation of AVG concepts. In contrast to the studies described in section 4.2, we are not trying to predict future time estimates of different technology diffusion degrees. Hence, the typical forecasting function of the Delphi technique is very limited in this study.

The other, mentioned weaknesses of the Delphi technique are strongly related to the set-up of a Delphi study and the way in which the results are analysed. These operational, methodical issues will be dealt with in the next sections.

4.4 Set up of the present Delphi study

Our Delphi study is based on a questionnaire with pre-specified answers, repeatedly sent to a number of experts. In the subsection 4.4.1 the AVG concepts questioned are discussed. Next, the set-up of the questionnaire is presented in subsection 4.4.2. The procedure for selecting experts is given in subsection 4.4.3. The way in which the results will be analysed is presented in the next section.

4.4.1 The AVG concepts questioned

The plausible AVG concepts have been specified in chapter 3 and have been clustered into basic groups of related concepts, by assuming evolutionary developments to some degree. As such, seven plausible, evolving AVG concepts have been specified. Evidently, the concepts have to be further operationalised in order to enable experts to evaluate these concepts in a proper way. A major question in designing the questionnaire was which specific

systems had to be investigated, given the variety of plausible AVG concepts under development.

We focused on those concepts which are generally recognised as essential for the support of separate subtasks of driving as well as the total integration of them called the autopilot (Shladover, 1995; Diebold Institute, 1995; Stevens, 1997). In terms of the AVG concepts as presented in Table 3-4, this implies a focus on the concepts 1,2,3,4 and 7. The implementation of intermediate AVG concepts which consist of combined functionalities (i.e. longitudinal and lateral support) at either warning or assisting automation level (concept 5 and 6 in Table 3-4), are assumed to encounter similar conditions as the elements the concepts can be constructed of. Consequently, the following AVG functionalities are of interest:

- speed/time headway keeping: detects the preceding vehicle and supports a driver by maintaining a correct distance between the vehicles (e.g. adaptive cruise control);
- front obstacle collision avoidance: the driver is warned and/or the vehicle is temporarily automatically controlled in case of a potential collision with a moving or stationary front obstacle;
- lane keeping support: warns a driver and/or controls the vehicle temporarily in case of impending road departure;
- side obstacle collision avoidance: the driver is warned and/or the vehicle is temporarily automatically controlled in case of collision danger during lane changing and merging;
- autopilot: all driving tasks are fully automated by this system, allowing 'hands-off' and 'feet-off' driving.

Of course, for each concept further distinctions can be made in terms of specific operating characteristics. As different perceptions of a functionality could give different opinions, each expert has been asked to give the expected system specifications related to near-term applications by means of textual descriptions. These descriptions have been used in this study in order to interpret individual expectations more adequately in relation to other expert opinions.

4.4.2 The questions

The Delphi study aims at exploring the conditions for the implementation of plausible AVG concepts. This objective has been translated by questioning experts on:

- the initial market characteristics of the different AVG concepts;
- the barriers which obstruct market introduction and/or further deployment.

Regarding the initial market prospects of AVG concepts, experts were asked to indicate the period of market introduction and the user costs for a system. A distinction was made

between 'warning only' devices and systems which actually intervene the driver, as we are interested to know to what extent the level of system automation is expected to influence the moment of market introduction and user costs. Furthermore, respondents had to indicate for which type of user group(s) and for which specific road(s) a system will initially become available (during the first five years after market introduction). Pre-specified answer-categories were presented in the questionnaire and the respondents were asked to tick the category according to their opinion.

Given the initial market prospects for the different systems, the next step is to assess the factors which could obstruct a system's market introduction and/or further developments. Dominant decision makers within this market determining future developments are system designers, vehicle operators and road operators, each having their own specific problems, related to different system performance levels, driver performance and traffic performance respectively (Morello, 1994). Several issues were listed for each performance indicator, based on review of recent literature. The respondents were invited to add missing barriers during the first round of interrogation in order to include them in the following rounds. Respondents were asked to evaluate to what degree they expected an issue to obstruct the market introduction of a system and/or further developments. Furthermore, some general obstacles related to all decision makers had to be assessed. The respondents had to indicate their opinion on a scale from 1 to 5, a '1' representing a very important barrier and a '5' representing a very unimportant barrier. An example of a question is given below (Table 4-3). The questionnaire is fully given in Appendix A.

By setting up the questionnaire as indicated above, the interpretation of responses, intermediate feedback and final results is straightforward, thus minimising the space for subjective input by the Delphi organiser. As such, the opinion of the panel is directly represented.

Table 4-3: An example of a question within the Delphi survey

Question: Please indicate to what degree each of the following driving barriers will have to be improved further to provide the systems' market introduction and/or further development:

systems	SHK	FCAS	LKS	SCAS	AP
driving barriers	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
counteracting driving behaviour	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
possible increase in driver workload	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
possible decrease in driver workload	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0

SHK = speed headway keeping; FCAS = front obstacle collision avoidance; LKS = lane keeping support; SCAS = side obstacle collision avoidance; AP = autopilot. 1 = very important barrier; 2 = important barrier; 3 = moderate-important barrier; 4 = unimportant barrier; 5 = very unimportant barriers.

4.4.3 The selection of experts

As mentioned before, the selection of experts is always considered an important issue in the set up of a Delphi study, as the quality of a Delphi outcome strongly depends on the quality and completeness of the input. In general, the selection of experts logically breaks down into two parts (Helmer, 1988):

- the determination of the variety of expertise needed for the problem under study, and
- the identification of the experts for each part of this variety.

The experts for this Delphi study were selected based on the following procedure. The areas that required expertise were listed, both within the fields of technology development and system implementation (e.g. system performance, driver performance, traffic performance next to system deployment, planning, markets, policy making). Recent literature was scanned to identify persons with recent publications in these fields. Here, the PATH database, available from the Internet, was used. This bibliographic database contains references to all aspects of Intelligent Transportation Systems, with an emphasis on research related to the PATH programme, such as Automated Highway Systems. It currently contains almost 15.000 records with abstracts of papers, articles and research reports of research results.

A first search within the database resulted in a group of about 350 persons. This group was further scanned to identify an expert panel of prominent persons. Ninety-four experts were selected, based on their publications, affiliation (government, industry, research institute, and consultancy) and country (Europe, United States, and Japan), in order to get an optimal representation of relevant expertise.

In order to maximise the completeness of the expert panel, each selected expert was asked to name the main experts he or she knew in this field. If these recommended experts had not already been selected, they were included in the panel. By doing so, another 23 experts were added to the panel, resulting in a final number of 117 experts.

Finally, in order to check the expertise, these experts were asked to mention their degree of expertise on each system under consideration, ranging from specialists for all systems to no in-depth expertise for any system.

Of course, this selection procedure does not fully guarantee the inclusion of all expertise needed. Some bias might be induced as, for instance, the database used does not cover all publications in this field, some experts in this field might not publish on their activities undertaken in this field, some experts might not be recommended due to personal or strategic considerations of the recommending participant, etc. However, we do believe that the selection of experts in the presented way above does optimise the quality and completeness of the expert panel.

Next to the required attention for the selection of experts, the possibility and willingness of experts to participate in a Delphi study has been argued as problematic. In order to motivate experts to participate in our study, they were promised a final report. Furthermore,

to prevent high dropout rates between rounds, reminders were sent after each round. These measures should encourage experts to fully participate in this study

4.5 Analysing the results

We already argued the importance of determining the consistency of individual opinions between consecutive rounds, before one can draw conclusions on valid consensus within a panel. In subsection 4.5.1 a measure is given to determine this consistency. Furthermore, the data collected enables us to examine whether a barrier is more, or less, important than another barrier. In subsection 4.5.2, an approach is specified to analyse the relative importance of barriers.

4.5.1 The stability of individual opinions within Delphi studies

In order to avoid 'false consensus', first the consistency of individual answers between rounds should be checked. Several experts might change their judgements substantially between two rounds, whereas the average group opinion as well as the dispersion of opinions does not change, due to compensating effects at the individual level. Only if the individual answers are consistent between consecutive rounds, the consensus indicator can be validly interpreted. The question is how to operationalise and measure the individual consistency.

Chaffin & Talley (1980) link consistency of individual judgements to the so-called 'individual stability of answers': the idea that the response frequencies of two subsequent rounds do not differ significantly from each other. A logical way to test stability in this way is to use the Chi-square test, as one is interested in the dependence of two variables: the responses of round i and the responses of round $i+1$ (in case of using the Chi-square test, independence among two consecutive rounds is assumed and a test statistic is computed based on the difference between the observed response frequencies and the expected response frequencies; should this test statistic be too large at a certain significance level, then dependence is concluded). However, the applicability of Chi-square test is related to the number of observations. For a low number of observations, i.e. less than five, misrepresentations might occur. Within Delphi studies, one is often confronted with a low number of observations as the numbers of experts is usually low. Furthermore, in case of the Chi-square test no information is given about the degree of stability between consecutive rounds. Therefore, in order to measure the dependence as well as the degree of stability of individual answers between consecutive rounds, Chaffin & Talley propose to use a stability index as defined as follows.

Suppose for instance that the response frequencies over two consecutive rounds are presented in the contingency Table 4-4. Suppose A_1 to A_5 represent the response options presented to the experts in round i , and suppose B_1 to B_5 represent the same response options presented to the experts in round $i+1$. Now, for cross classified data, the index of

stability, λ_B , is defined as the proportional reduction in the probability of error in predicting the responses of round $i+1$ (B), given the answers in round i (A), i.e.:

$$\lambda_B = \frac{P(\text{error choosing } B | A \text{ unknown}) - P(\text{error choosing } B | A \text{ known})}{P(\text{error choosing } B | A \text{ unknown})} \quad (4.1)$$

where,

(error choosing B | A unknown) represents the prediction of a wrong category of B if the category of A is unknown, and

(error choosing B | A known) represents the prediction of a wrong category of B if the category of A is known.

The values of λ_B , can be calculated straightforward from contingency tables in which the response frequencies over consecutive rounds are presented:

$$\lambda_B = \frac{\sum_j \max_k f_{jk} - \max_k f_{.k}}{n - \max_k f_{.k}} \quad (4.2)$$

where,

f_{jk} = number of respondents who voted for the j -th response interval in round i but voted for the k -th response interval in round $i+1$; the frequency observed in cell (A_j, B_k)

$\max_k f_{.j}$ = highest frequency for the j -th response interval at the i -th round; the highest frequency in column A_j

$\max_k f_{.k}$ = highest total frequency for among the k -th response intervals at round $i+1$, the highest marginal frequency of the rows B_k

n = total observed frequencies

The stability index varies between one and zero, a one indicating perfect stability and a zero indicating total instability. Suppose for instance the response frequencies f_{jk} over two consecutive rounds as presented in the contingency Table 4-4. According to this response, most respondents indicate the same response categories over the different rounds and intuitively one expects nearly stability. The stability index λ_B for these response frequencies is: $(13 + 6 + 16 + 2 + 3) - 18 / (45 - 18) = 0.8148$, a relatively high dependence and one may conclude stability.

Table 4-4: Exemplary response frequencies over consecutive rounds

response interval	(round i)					Total
	A ₁	A ₂	A ₃	A ₄	A ₅	
B ₁	13 ¹					13
B ₂	1	6	1	1		9
B ₃			16	1	1	18
B ₄				2		2
B ₅					3	3
Total	14	6	17	4	4	45

¹ 13 respondents indicated category A₁ in the first round and B₁ in the second round

In this study the stability of individual expert opinions over subsequent rounds is measured and used as a stopping criterion. Next, the level of consensus within the panel is determined for each issue questioned. For those issues for which consensus is lacking within the panel, experts are invited to indicate the motivation for their opinion regarding these issues in an additional round. The group opinion on an issue is represented by the median and the degree of consensus by the interquartile range, as measurements are made at an ordinal level. The median represents the value for which yields that half of the scores is lower and half of the scores is higher, and the interquartile range represents the interval which contains the middle 50% of the scores.

In this study the importance of barriers regarding the implementation of an AVG system has to be evaluated on a five-point scale from '1' to '5': a '1' expressing 'very important'; a '2' expressing 'important'; a '3' expressing 'moderate important'; a '4' representing 'unimportant', and a '5' expressing 'very unimportant' (see Table 4-3). Given this scale, it is assumed in this study that an interquartile range of 1 to 3 (or smaller ranges) and an interquartile range of 3 to 5 (or smaller ranges), represent consensus among the panellists. These ranges express that the panel evaluate a barrier important respectively unimportant. In contrast, the range (2-4), or larger ranges are assumed to represent disagreement among the experts, as these ranges do not indicate a clear tendency regarding the (un)importance of a barrier.

4.5.2 The importance of barriers

The data obtained in this study contains further information with respect to the relative importance of barriers related to different systems. In order to determine the most dominating barrier for each pair of barriers across different systems, the degree to which the respondent scored higher or lower on an issue as compared to the other issue, has to be

analysed. This type of analyses is based on the concordance and discordance of scores regarding pairs of barriers (Blalock, 1979). We will briefly explain the meaning of (dis)concordant pairs using an example. Suppose for instance that for a system two barriers, b_1 and b_2 , have been evaluated by three respondents, r_1 , r_2 and r_3 , according to the scores as presented in Table 4-5. The respondents r_1 and r_2 have evaluated barrier b_1 and b_2 in similar order (barrier b_1 is evaluated to be more important than barrier b_2). As such the pair (r_1, r_2) is defined as concordant. In contrast, a pair of scores is defined as discordant if the barriers are evaluated in reverse order. For instance, the pair (r_1, r_3) is discordant as barrier b_1 is evaluated to be more important than barrier b_2 by respondent r_1 respectively less important by respondent r_3 .

Table 4-5: Concordant and discordant scores regarding a pair of barriers

barriers	respondents	respondent r_1	respondent r_2	respondent r_3
barrier b_1		1	2	3
barrier b_2		2	3	1

1 = very important barrier; 2 = important barrier; 3 = moderate-important barrier;
4 = unimportant barrier; 5 = very unimportant barriers.

By counting the number of concordant and discordant pairs of scores it is possible to rank the barriers in terms of their importance for different systems. In this subsection the formal procedure for this type of analyses is described. The procedure used here is based on the quantitative concordance method, a well-known method within multi-criteria analysis of alternatives (Voogd, 1983).

Suppose n systems have been evaluated with respect to m barriers. This can be represented by an $(m \cdot n)$ matrix E containing the evaluation data $e(i, j)$: the score of the j -th system ($j = 1, \dots, n$), with respect to the i -th barrier ($i = 1, \dots, m$). In order to determine the dominance score $d_j(i, i')$ between barrier i and barrier i' for a system j , the frequency is calculated that respondents evaluated barrier i to be more important than barrier i' minus the number of times barrier i was evaluated less important than barrier i' :

$$d_j(i, i') := \text{frequency}[e(i, j) > e(i', j)] - \text{frequency}[e(i, j) < e(i', j)] \quad (4.3)$$

The dominance score $d(i, i')$ for the relation between barrier i and barrier i' for all systems is given by summing up the dominance scores calculated for each system separately:

$$d(i, i') := \sum_j d_j(i, i') \quad (4.4)$$

By computing $d(i, i')$ for each pair (i, i') of barriers, a $(m \cdot m)$ dominance matrix D is obtained. By definition of $d_j(i, i')$, this matrix is skew-symmetric ($d(i, i') = -d(i', i)$) and its diagonal elements are zero ($d(i, i) = 0$). The dominance score $d(i)$ of barrier i is now given by summing up the row elements of the i -th row of matrix D :

$$d(i) := \sum_i d(i, i') \quad (4.5)$$

Finally, a standardised dominance score $\underline{d}(i)$ is obtained by dividing $d(i)$ by the sum of absolute values of dominance scores for all i 's:

$$\underline{d}(i) := d(i) / \sum_i |d(i')| \quad (4.6)$$

The relative, overall dominance of the barriers can now be deduced from this information for each set of systems desired. This procedure is used in this study to determine a ranking of barriers for all the supporting systems together on the one hand (speed headway keeping, front obstacle avoidance, lane keeping and side obstacle avoidance) and the autopilot on the other hand.

4.6 Conclusions and discussion

In this chapter a Delphi study has been set up to evaluate the conditions for the implementation of AVG concepts. Different expert judgement techniques have been explored and experiences from related studies have been reported.

It was concluded that the Delphi technique is most appropriate for our research goals, due to its proven validity, in terms of consistent results of the different studies, and limited use of research resources, as compared to other expert opinion techniques. Furthermore, the relevant findings of other Delphi studies in the field of transport telematics indicate that the Delphi technique to be a well-established tool which can be applied straightforward.

However, a further description and analysis of the Delphi technique points out that this technique has some serious limitations, which should be taken into account in setting up a Delphi study. Otherwise, the results might be unreliable and invalid and thus useless.

For instance, experiences in other fields show that the forecasting ability of the Delphi technique is low. In our study the aim is not to forecast discrete time moments of technology diffusion but to evaluate conditions which might obstruct the implementation. Hence, the forecasting nature of our study is highly limited. Furthermore, the frequently used stopping criterion for the number of interrogation rounds within Delphi studies, i.e. some desired level of consensus within the expert panel, appears to be insufficient. Analysis on the individual stability of answers of consecutive rounds is essential to draw valid conclusions in this context.

Other pitfalls related to the execution of Delphi studies have been mentioned and it appears that these disadvantages can largely be prevented by taking appropriate measures when setting up a Delphi study. Now that the set-up of the Delphi and the protocol for analyses has been elaborated, the results of the Delphi study can be discussed. This will be done in the next chapter.

Chapter 5.

Expert opinions on AVG implementation

This chapter presents the outcome of a Delphi study among experts, which has been carried out between May 1997 and October 1997¹. In this study the plausible AVG concepts, as identified in Chapter 3, are analysed in-depth, in terms of conditions assumed for implementation. Several experts have, by means of the Delphi technique elaborated in the previous chapter, been questioned on the initial market prospects of basic AVG systems and the possible barriers for the implementation of these systems. In section 5.1 the survey response and the profile of the experts participating in this study are presented. The expectations of the expert panel with regard to the early markets of the different AVG systems are presented in section 5.2. Section 5.3 concentrates on today's barriers for the introduction and/or further developments of systems. Finally, in section 5.4, the main conclusions are drawn.

¹ The results of this study are presented in Marchau & Van der Heijden (1998)

5.1 Survey response and profile respondents

This Delphi study was based on a questionnaire with specified answer options, as presented in the Appendix. This questionnaire was sent to the expert panel in subsequent rounds. After each round, the group opinion on the different issues was included in the questionnaire for the following round. The experts were then invited to reconsider, and if desirable, to change their former, individual opinion.

The number of rounds of the study was based on the stability of individual opinions over different rounds and a desired level of consensus within the expert panel. The consistency of individual opinions over the different rounds was calculated by the stability index as presented in subsection 4.5.1. The results are summarised in the Appendix (section A.3). Based on these results, the number of rounds could have been limited to two interrogation rounds. However, besides stability, the degree of consensus within the expert panel has been considered. The consensus and dispersion were respectively measured in terms of the median (the value for which yields that half of the scores is lower and half of the scores is higher) and the interquartile range (the interval which contains the middle 50% of the scores). After two rounds, consensus within the response group was considered sufficient for most issues but, not for all of them. Where consensus was lacking, respondents were invited to review their opinion in a third round and, more important, to comment on their final choice, irrespective of changing their previous answer.

In the first round of the Delphi study, 117 participants were approached, 65 of which returned a filled-in questionnaire. Fifty out of the 65 questionnaires sent out in the second round were returned. In the third and final round, 40 out of 50 questionnaires were returned. These response rates are quite satisfying, compared to other studies described in literature and given the considerable amount of work asked from the respondents for filling in the questionnaires. In Table 5-1 the response is further specified. The response over different rounds is presented with respect to the participants' geographical background and affiliation. Clearly, respondents from relevant continents and organisations were well represented in the panel. It was tried to stimulate the participation in this study by promising the participants an overview of the main survey results. Reminders were sent after each round, in order to limit the drop-out rate of participants during consecutive rounds.

Some participants being invited for the first round indicated that they lacked time for filling in the questionnaire. One industrial expert could not fill in the questionnaire as this 'would reveal confidential information with regard to his company, especially the information about the schedule of product development'. The first round response of invited American participants was quite low, as compared to the response rates of their European and Japanese colleagues. The response rate of university participants was also somewhat lower as compared to the other groups. This might be due to the fact that this group as compared to the other groups, is less involved in market introductions of products and consequently more indifferent to the type of issues questioned in this Delphi study.

Table 5-1: Response over rounds regarding geographical background and affiliation

background respondents	questionnaires sent out	1 st round response	2nd round response	3rd round response
<i>geographical:</i>				
Europe	58	39	30	21
North America	42	16	13	12
Japan	17	10	7	7
<i>affiliation:</i>				
government	12	7	6	6
industry	31	16	13	9
research institute-consultancy	35	24	17	12
university	39	18	14	13
total	117	65	50	40

As indicated above, the third round of the Delphi questionnaire differed from the first and the second round. This final round was mainly a qualitative round in which respondents were asked to argue those issues on which consensus was, in our opinion, still lacking after the two rounds. Although respondents had the opportunity to revise their opinion on these issues as well, most respondents preferred to comment only on their previous, second round answers. Therefore, the 50 respondents of the second round are considered the final panel in our study. This implies that also the second-round answers of the ten non-responding panellists in the third round are taken into account for determining the final group opinion, assuming that these respondents would not have changed their opinion in the third round.

All the experts who mentioned their professional training had a university degree, including 1 expert with a bachelor's degree, 17 with a Master's degree, and 23 with a PhD. The majority of these respondents had an engineering degree: 3 respondents held a degree in computer engineering, 5 in electrical engineering, 8 in mechanical engineering while 6 respondents held other engineering degrees or did not further specify their degrees. Furthermore, 5 respondents held a degree in mathematics and/or physics, 5 in psychology, 1 in economics and 2 in technology management. Of the 48 respondents who entered their age, 21 were between 30 and 39, 17 between 40 and 49, 6 between 50 and 59, and 4 between 60 and 68. Only 4 out of the 50 panellists were female.

The size of the organisations in which the respondents worked, varied in workforce from small consultancy companies with a few employees to research organisations with some thousands of employees, to thousands of employees within universities and to several tens of thousands within industrial companies and public authorities. Of the 50 respondents, 43 indicated the number of persons they supervised (see Table 5-2). Thirty-two respondents did actually have some supervisory responsibility, 3 of which for the entire organisation.

Despite the supervisory activities of many respondents, most respondents indicated that they had a research function (Table 5-2). Some respondents indicated they had more than one profession.

Table 5-2: Supervisory responsibility and profession(s) of respondents

persons supervised	number of respondents	profession	number of respondents
0	11	project manager	5
<10	21	executive – director	15
10-100	10	researcher – engineer	32
>100	1	consultant	6

The expertise of the selected participants was checked by asking them to indicate the degree of expertise they had for each AVG system on a four-point scale, varying from no expertise to major expertise. The results of this measurement are summarised in Table 5-3. Between 86% (for speed headway keeping) and 58% (side obstacle collision avoidance) of the panel indicated that he or she had at least average expertise on a system. Overall, the expertise of the panel is considered adequate for this Delphi study (Table 5-3). Each respondent appeared to have at least minor expertise on one system. Only 3 respondents (6%) indicated that they had minor expertise on each AVG system questioned.

Table 5-3: Expertise of panel with respect to different systems (n=50)

system expertise	speed headway keeping	front obstacle coll. avoidance	lane keeping support	side obstacle coll. avoidance	autopilot
major	38%	24%	24%	16%	30%
average	48%	52%	46%	42%	34%
minor	14%	24%	28%	36%	32%
no expertise	0%	0%	2%	6%	4%

We concluded that our group of respondents to be somewhat homogeneous. The average profile of the respondent was that of a middle-aged man with a university education in a technical discipline, mostly occupied with research activities in the field of development of AVG systems, next to some managing activities within research programmes. This could be expected, as past developments of AVG systems were strongly technology-based. Despite the homogeneous nature of the response group, the expertise of the panel is considered to be adequate for this Delphi study.

5.2 Early markets

In Table 5-4 the results are presented of the analysis concerning experts' opinions on the period of market entrance of the various systems. As stated in section 1.2 a speed headway system is commercially available in Japan. Several other speed headway keeping systems with varying operating characteristics are expected to enter the market before 2000. The panel described various detection capabilities of moving target vehicles ahead (target distance, target speed and target size) and different types of intervention (throttle only or

some limited braking included). Some respondents indicated that the driver will be in charge of an adjustable time headway setting. One respondent stated that "Speed headway keeping will be on the market in 1998. It will be radar based and realise an intelligent cruise control".

A limited number of the respondents (30%) indicated to be familiar with the fact that front obstacle warning systems are already available on a small scale. Other respondents were not acquainted with these developments or might have considered these applications not to meet the functional requirements of front obstacle warning systems in general, as these systems only support the avoidance of rear-end collisions between vehicles, not more general obstacles. A majority of respondents (54%) expects the availability of front obstacle warning systems in the period 2000-2005. Furthermore, there appear to be varying expectations among respondents about the systems' capabilities of detecting obstacles and decision making on appropriate actions. Some respondents indicated that detection of small obstacles is still difficult. These systems will initially "detect only vehicles and motorcycles" or "only large obstacles". "Reliability, false alarms and liability are too serious problems for near term deployment of control systems". The different expectations of respondents on future technological progress in this area are reflected in a broad time forecast of availability of front obstacle collision avoidance control systems, i.e. somewhere between 2000 and 2020.

Table 5-4: Expected period of market introduction of each system (n=50).

system: period:	speed headway keeping		front obstacle coll. avoidance		lane keeping support		side obstacle coll. avoidance		autopilot
	warn - control		warn - control		warn - control		warn - control		
(1) before 2000	64%	50%	30%	2%	8%	0%	20%	0%	0%
(2) 2000-2005	30%	32%	54%	34%	72%	12%	34%	10%	0%
(3) 2005-2010	0%	10%	12%	28%	10%	52%	26%	28%	12%
(4) 2010-2020	2%	4%	2%	30%	6%	28%	14%	38%	36%
(5) after 2020	0%	4%	0%	6%	2%	6%	2%	18%	42%
(6) never	0%	0%	2%	0%	0%	0%	0%	2%	6%
median	1 ²	1.5	2	3	2	3	2	4	4.5
(interq. range)	(1-2) ³	(1-2)	(1-2)	(2-4)	(2-2)	(3-4)	(2-3)	(3-4)	(4-5)

¹64% of the respondents indicated that speed headway keeping in warning mode will become available before 2000; ²group opinion by median; ³degree of group consensus by interquartile range, i.e. the interval containing the middle 50% of responses.

Table 5-4 further illustrates a high degree of consensus among the respondents (72%), that lane departure warning systems will be introduced in the time period 2000-2005. At present, various systems are subject to testing programmes. They mainly differ in terms of the need for infrastructure modifications. Systems which take temporary control are not expected to be commercially available before 2005.

As in the case of front obstacle warning systems, most respondents are not familiar with today's availability of some applications in the field of side obstacle collision avoidance or they did consider blind spot warning devices not to meet the functional requirements of a general side obstacle warning system. "Acoustic systems which warn the driver against side obstacles has been marketed 4 years ago". However, warning systems are, by most respondents, expected within the time period 2000-2005. Applications could be based e.g. on the activation of turn signals, looking for general side obstacles or only blind spot obstacles. In this case temporary control is expected much further away. One respondent indicated that "side obstacle avoidance may never become available in control mode as a separate system, it would be easier to go directly to fully automated driving".

The technologically most advanced system, the autopilot, is as expected predicted for the remote future. Thirty-six percent of the respondents do not expect the introduction of the autopilot before 2010 and even 42% of the group do not expect its introduction before 2020; only 3 respondents (6%) were of the opinion that the autopilot will never be introduced. Several concepts are subject to research in this field, varying from autonomous vehicles to cooperating vehicle-roadway systems.

The extent to which the increase in intervening functionality is expected to influence the moment of market introduction of a system is illustrated by the median panel opinion in Table 5-4. Except for speed headway keeping, intervening systems are systematically expected to be introduced some years later than warning devices.

Table 5-5 summarises the panel's prediction on the consumer costs of the various systems during market introduction. Most respondents expect warning devices to fall within the \$500 and \$1000 range. Systems which actively intervene the driver are not only expected to be introduced later on the market, but also to be more expensive than warning devices. This is expressed by the respective median panel opinion in Table 5-5. Most respondents expect market prices between \$1000 and \$1500 for devices which take temporary control. As several variants of each system are expected to be marketed, the estimated consumer costs can also vary considerably. This will a.o. depend on the key technologies used, the system's specific support capabilities, the type of interfaces, the road network applicability, etc.

Furthermore, cost estimates become probably more difficult in case systems development and market introduction are expected in the remote future. The consumer costs for the autopilot are the most uncertain; estimates vary between \$1500 to \$5000.

Table 5-5: Expected consumer costs during the market introduction period (n=50).

system cost interval:	speed headway keeping		front obstacle coll. avoidance		lane keeping support		side obstacle coll. avoidance		autopilot
	warn - control		warn - control		warn - control		warn - control		
(1) <\$500	24% ¹	8%	20%	8%	22%	8%	18%	6%	2%
(2) \$500-\$1000	54%	24%	52%	8%	44%	6%	42%	6%	2%
(3) \$1000-\$1500	4%	42%	18%	40%	12%	36%	16%	28%	2%
(4) \$1500-\$2500	2%	14%	2%	20%	8%	20%	10%	26%	20%
(5) \$2500- \$5000	2%	4%	2%	12%	2%	12%	2%	16%	32%
(6) over \$5000	0%	2%	0%	2%	0%	2%	0%	2%	20%
median	2 ²	3	2	3	2	3	2	4	5
(interq. range)	(1-2) ³	(2-3)	(2-2)	(3-4)	(1-3)	(3-4)	(2-3)	(3-4)	(4-6)

¹24% of the respondents indicated that speed headway keeping in warning mode will cost the consumer less than \$500; ²group opinion by median; ³degree of group consensus by interquartile range, i.e. the interval containing the middle 50% of responses.

The experts were further asked to indicate the most likely roads and user groups for which early AVG systems will become available. The results are presented in Table 5-6. In this study it we did not research the influence of the degree of system control, i.e. warn or intervene, regarding the type of roads and user groups for which systems are expected to initially become available. The choice of not asking this was based on the trade-off between increased amount of work for the respondents and the necessity of this information for our research.

Today's motorways are generally considered to be the most appropriate road type for initial use of speed headway keeping, obstacle avoidance and lane keeping systems. A minority of the respondents expect these systems to become available for rural roads (no crash barriers, grade crossings, etc.) or urban roads (presence of bicycles, pedestrians, etc.). A great majority of the panel (86%) expects the autopilot to become initially available only in terms of dedicated lanes with equipped vehicles.

The panel's dominant opinion that all systems which partially support the driver will become available during market introduction for motorways might be attributed to the fact that the automation of driving tasks becomes more complex at lower road levels. This was supported by the response patterns of the respondents: indicating use (implementation) of a system at a lower road type was mostly followed by indicating use at a higher road type.

For speed headway keeping and lane keeping support, the panel considers rural motorways more likely than urban motorways. As with conventional cruise control, the use of speed headway keeping within dense traffic areas could be less comfortable. Furthermore, data on crash types points out that run-off road crashes occur most within rural areas (Pomerleau et al, 1997). Hence, lane keeping support systems might have a higher potential to improve safety on rural motorways as compared to urban motorways.

Table 5-6 further gives an overview of the panel's expectations about the first user groups. Freight operators are generally expected to be an important user group for each

system. Safety and/or efficiency gains might be of particular importance for this market segment. For instance, as the impacts of heavy-vehicle collisions are often much more severe than those of light vehicles (and consequently generate more costs), the avoidance of crashes with these heavy vehicles becomes more important and economically attractive. In general, the ratio of AVG equipment cost to vehicle costs is much lower for heavy vehicles than for passenger cars, as the average costs for heavy vehicles are much higher. As such, heavy-vehicle operators are likely to be the first user groups of AVG (Kanellakopoulos & Tomizuka, 1997).

Next to freight operators, business drivers are expected to be a second important user group of most systems during initial market introduction. The relative lower expected costs for speed headway systems might also attract commuters and leisure drivers.

Table 5-6: Expected type(s) of roads and user groups for first system applications (n=50).

system	speed headway keeping	front obstacle coll. avoidance	lane keeping support	side obstacle coll. avoidance	autopilot
<i>a. road types:</i>					
dedicated lanes	28% ¹	24%	34%	26%	86%
rural motorways	84%	68%	82%	64%	34%
urban motorways	66%	68%	50%	72%	20%
rural roads	28%	38%	26%	26%	2%
urban roads	8%	28%	2%	26%	0%
no opinion	0%	2%	4%	4%	4%
<i>b. user groups:</i>					
freight operators	76% ²	78%	80%	78%	66%
commuters	50%	38%	30%	36%	36%
leisure drivers	48%	38%	28%	22%	16%
business drivers	70%	58%	56%	48%	44%
elderly-disabled	20%	12%	14%	18%	14%
bus operators	14%	18%	10%	14%	14%

¹28% of the respondents expects that this system will become first available on dedicated lanes;

²76% of the respondents expects that this system will become first available for freight operators

As stated in subsection 4.4.3, the outcome of an expert opinion on an issue partially depends on the characteristics of the experts. Although the number of respondents is too small in our survey to allow for a statistical analysis of differences between subgroups, some different trends in responses have been found according to the respondents' geographical background and the degree of expertise on a system.

Generally, European respondents were less optimistic about both the expected period of introduction of the systems and the expected consumers' costs, as compared to their American and Japanese colleagues. Except for speed headway keeping, non-European respondents also dominated the panel's opinion on the types of roads and user groups for which systems will become available during market introduction. For speed headway

keeping relatively more European than non-European panellists indicated that they expected this system to become first available for urban motorways and business drivers.

Respondents indicating to have major expertise on a system, i.e. specialists, were generally found more optimistic than the rest of the group with respect to the initial applicability on different road types and the first user groups of systems. Motorways and dedicated lanes (Table 5-6a) received higher scores with respect to the likeliness of application of systems by specialists, as compared to respondents who did not have major expertise on the systems. With respect to future systems users (Table 5-6b), 63% of the specialists expected that speed headway keeping will become available for commuters and leisure drivers, 60% held the view that the autopilot will become available for commuters, and 54% held the view that the autopilot will become available for business drivers.

5.3 Impediments for further developments

The previous chapter analysed the expert opinions on the basic characteristics of market introduction of the various systems. In this chapter potential barriers to implementation of these systems are evaluated. In subsection 5.3.1 the likelihood that the systems will contribute to general transport policy goals, is considered. Barriers related to technology and driving behaviour respectively, are evaluated in the subsections 5.3.2 and 5.3.3. Finally, general impediments to implementation are discussed in subsection 5.3.4.

5.3.1 Uncertain contribution to public policy goals

Table 5-7 presents the group opinion on the likelihood that the variety of electronic systems will contribute to general public policy goals. Furthermore, given these scores on all systems, the ranking of the most uncertain contributions to the most certain contributions across the set of all systems which support part of the vehicle driving task respectively the autopilot has been determined. In order to determine the most uncertain contribution to policy goals, the degree to which respondents scored higher or lower on an issue compared to other issues has been analysed by concordance analysis (subsection 4.5.2). The analysis is given in the Appendix (section A.4). In this section, only the results will be discussed.

On most issues consensus has been reached among the respondents during the different interrogation rounds. However, on some issues no consensus was reached within the group. They have been indicated by bold figures in Table 5-7. The respondents were explicitly asked in the third interrogation round to express their explicit view regarding these different opinions. They will be discussed at the end of this subsection.

For some systems the panel indicated that they expected these systems to certainly contribute to a policy goal whereas for other systems this contribution was evaluated uncertain. The possible safety improvement of front obstacle avoidance was considered certain by the panel, next to an increased driving convenience of speed headway support and the autopilot. Looking at all those systems which support the driver partially (speed headway support, front-side obstacle avoidance and lane keeping), the contribution to the

increase in road capacity of these 'supporting' systems has been evaluated uncertain by the panel. This is clearly shown in Table 5-7. As for safety improvement, increase in driving convenience and the reduction of environmental impacts, similar conclusions cannot be drawn directly as these median scores are less consistent.

The ranking of most uncertain contributions to most certain contributions across the total set of supporting systems reveals the following. Efficiency gains and the reduction of environmental impacts of supporting systems are ranked at the first and second position respectively. The likelihood of contributing to increased driving convenience comes at the third position. Most likely is the contribution of assisting systems to the reduction of fatalities and accident severity respectively. In contrast, the contribution of the autopilot to accident severity reduction is ranked first in uncertainty, followed by the reduction of both environmental impacts and fatalities. The most likely impacts of the autopilot appear to be the increase in road capacity and driving convenience.

Table 5-7: Likelihood of system contribution to general transport policy goals (n=50).

system	estimated contributions by panel					ranking of contributions	
	SHK	FCAS	LKS	SCAS	AP	all support systems	AP
reduction of fatal accidents	3 (2-4) ²	4 (3-4)	3 (3-4)	3 (2-4)	3 (2-5)	[4] ³	[3]
reduction of accident severity	3 (2-4)	4 (3-4)	3 (3-4)	3 (3-4)	3 (2-4)	[5]	[1]
increase of road capacity	2 (2-3)	2 (1-3)	2 (1-3)	2 (1-3)	3 (3-5)	[1]	[4]
increase of driving convenience	4 (4-4)	3 (2-3)	3 (3-4)	3 (2-3)	4 (3-5)	[3]	[5]
reduction of environm. impacts	3 (2-3)	1 (1-3)	1 (1-2)	1 (1-2)	3 (3-4)	[2]	[2]

group opinion by median: 1=highly uncertain; 2=uncertain; 3=moderate certain; 4=certain 5=highly certain; ²group consensus by interquartile range, i.e. the interval containing the middle 50% of responses (figures printed bold refer to issues on which consensus within the panel was lacking); ³ranking position of policy goal by concordance analysis

Next to the possible road capacity gains of the autopilot (printed bold in Table 5-7), the panel remained divided about the possible safety improvements of both speed headway keeping and the autopilot.

To explain their opinion on an uncertain contribution of speed headway support to traffic safety, respondents argued that this system will only support drivers in avoiding rear-end crashes "which is about 5% of all fatal crashes", in addition to the fact that "these crashes often involve a stopped preceding vehicle and it is not clear whether these systems will be capable of dealing with these cases". Furthermore, "drivers could explore a more risky driving behaviour" and "become less vigilant to the other obstacles", so that "adapterial behavioural mechanisms could partially cancel technical benefits". Respondents considering the contribution of speed headway support to traffic safety rather certain, motivated their judgement by stating that this system "will provide extra warning to drivers and/or more rapid actuation in case of hazardous situations", "human errors will be cancelled and inattentiveness will be countermeasured". "It will lead to safer inter-vehicle

distances” so “drivers will have enough time to avoid an accident”. Furthermore, as “speed headway support implies smaller speed differences, both fatalities and accident severity will be reduced”.

The disagreement within the panel about the contribution of the autopilot to traffic safety is argued as follows. Some argue that safety benefits will require an “optimal condition of the system and the roadway” which is difficult to achieve: “to what extent traditional accidents will be mitigated can be estimated, but it is not possible to predict how many accidents will arise from new mechanisms caused by failures in system components or logic since they are not known”. The autopilot “may result in a small probability to large accidents (like in air traffic)”, or “accidents could occur on other roads”. Finally, “it is highly uncertain how these systems will interact with manual driving”. Summarising, most reservations were based on system technological uncertainties and the absolute dependability on the specific system configuration. Those respondents who were optimistic about the safety improvements of the autopilot assumed an “absence of malfunctioning system components” and highly restricted environments.

The lack of consensus within the panel on the issue of capacity improvements of the autopilot was also related to the feasibility of severe conditions under which this can be achieved. “If the autopilot will be implemented on dedicated lanes where non-automated traffic is excluded”, huge capacity gains are most likely. However, the way in which for instance “junctions, merges and ramps are designed and controlled”, together with safety restrictions, “may reduce theoretical capacity gains considerably”.

5.3.2 Technological obstacles

Table 5-8 summarises the experts’ opinions regarding technical barriers for market introduction and/or further developments for the various systems as well as the ranking of the different barriers, according to these opinions regarding the set of all supporting systems and the autopilot respectively.

Both reliability and accuracy are considered most serious barriers to nearly all systems, except for speed headway keeping for which only the accuracy is considered an obstacle. All other technical barriers have been evaluated moderate important or even unimportant. For both front and side obstacle avoidance the type of appropriate action to be taken by the system, e.g. steering or braking when confronted with an obstacle, is evaluated a difficult issue. Moreover, the verification of software safety is an issue for these systems just as it is for lane keeping. The possibility of a system interfering with other in-car technologies is considered a moderate-important problem for all systems. Some respondents commented that “interference avoidance is typically a design issue”, “which can be relatively well engineered”. The autopilot is evaluated as the most technically complicated one: almost all the technical issues were evaluated as important to very important obstacles for implementation.

Overall, calculated by concordance analysis, the panel ranked reliability, accuracy and software safety verification subsequently as the most important technical barriers to the further development of support systems (see Appendix, section A.4) as for the autopilot,

these three issues were similarly ranked, followed by the complexity of decision-making algorithms.

Table 5-8: Technical barriers to further developments (n=50).

system	estimated barriers by panel					ranking of barriers	
	SHK	FCAS	LKS	SCAS	AP	all support systems	AP
technical barriers							
reliability: no support	3 ¹ (1-3) ₂	1(1-2)	2 (1-3)	1 (1-2)	1 (1-1.5)	[1] ³	[1]
accuracy: wrong support	2(2-3)	2 (1-2)	2 (1-3)	2 (1-2)	1(1-2)	[2]	[1]
interference of other systems	3 (3-5)	3 (3-4)	3.5 (3-4)	3 (3-4)	3 (2-4)	[7]	[7]
trade off comf./safety/effic.	3 (3-4)	3 (2-3.5)	3 (2-4)	3 (2-4)	2 (1-3)	[6]	[6]
complex. decision algorithm	4 (3-4)	2 (1-3)	3 (3-4)	2 (1-3)	1 (1-3)	[5]	[4]
software safety verification	3 (2-3)	2 (1-3)	3 (2-3)	2 (1-3)	1 (1-2)	[3]	[3]
technical durability	3 (2-4)	3 (2-3)	3 (2-4)	3 (2-3)	2 (1-3)	[4]	[5]

¹group opinion by median: 1=very important barrier; 2=important barrier; 3=moderate-important barrier; 4=unimportant barrier; 5=very unimportant barrier; ²group consensus by interquartile range, i.e. the interval containing the middle 50% of responses (figures printed bold refer to issues on which consensus within the panel was lacking); ³ranking position of barriers by concordance analysis

The panel disagreed on the technical interference possibility of the autopilot with other in-car systems as well as on the degree of difficulty of parameter trade-offs for obstacle avoidance and lane keeping.

Respondents emphasising the danger of interference argued that “the autopilot will be directly interconnected with many other systems and could therefore easily interfere”, in particular “under extreme conditions interference seems possible”. Furthermore, “there has been done very little work on interference, so the interaction between systems will be a barrier until it is studied”. The panellists who did not recognise interference as an obstacle for implementation of the autopilot expected this to be technically solvable in the future, as for supporting systems, or stated that this would not be an issue at all, as “there won’t be other systems to interfere with”. With regard to the issue of parameter trade-offs, one respondent considered this a very important barrier at international level for all supporting systems, ...”because of the different priorities that different countries place on safety, efficiency and comfort. It is also an important technical problem because of the need to ensure that genuinely hazardous situations are handled, while keeping the frequency of false alarms low enough to ensure customer acceptance and user confidence in the validity of the false alarms that are experienced. Drivers have very different preferences and styles of driving, and it is going to be quite difficult to define system operating characteristics that will be attractive to a large proportion of the driving population”. Another respondent considered parameter trade-offs less a problem for lane keeping and side obstacle

avoidance as “these do not demand extra spacing and high control gains whereas speed headway support and front obstacle avoidance do”. Panellists judging the trade-off not to be a problem, stated that initially “manufacturers will choose comfortable and safe settings” and “drivers will be able to adjust a few system-settings limited, according to their personal driving preferences”.

5.3.3 Barriers related to driving behaviour

Table 5-9 summarises the panel’s opinion on possible driver behavioural barriers for further development. The table indicates that the response group considers possible counteracting driving behaviour to be a serious barrier to all systems, although some respondents judged this of no importance for speed headway keeping. Drivers could take higher risks (like e.g. higher speeds, delayed braking, etc.), as they rely on the performance of their electronic equipment. This could neutralise, or even counteract, intended benefits of a system. Concerning the autopilot, the panel considered a possible decrease in driver workload and the danger of losing driving skills important obstacles to overcome.

Comparing the possible barriers across all the supporting systems again (see Appendix, section A.4), counteracting driving behaviour is ranked as the most dominating barrier, followed by the lack of driver education. Subsequently, the loss of driving skills, decrease in driver workload and increase in driver workload are ranked third, fourth and fifth. As for the autopilot, the possible counteracting behaviour is ranked first too, directly followed by the danger of losing driving skills and the lack of driver education.

The panel did not reach consensus on the degree to which counteracting driving behaviour could obstruct further developments of speed headway support systems. Arguments for considering this a serious barrier have already been put forward in previous sections of this chapter. It is assumed that drivers could rely too much on the system’s capabilities, both for situations for which the system is designed and for traffic situations the system is not meant to support, inducing more risky driving behaviour and inattentiveness. Only few respondents reacted to why they considered counteracting behaviour a minor issue. One respondent based his statement on his daily experience in driving with a speed headway support system. Others argued that “for existing cruise control this is not an issue and speed headway support is only an incremental step up from existing cruise control”.

Panellists further differed significantly in their opinion on the possible decrease in driver workload and the danger of losing driving skills as obstacles to further developments of the autopilot. “During the first few minutes after changing from the autopilot to manual driving an increase in driver workload could be a problem”. Furthermore, “system failures could require the driver to intervene”, and as he or she is probably less alert this could cause improper reactions. “Extensive use of the autopilot could further have major impacts on driving skills”. “If all driving tasks are automated, drivers will become deskilled, so if the system performance is less than 100% drivers will not be adequately skilled to take over”. Opponents state “the driver is unlikely to lose skills by using the autopilot, as most driving will continue to be under manual mode”. “The autopilot is not a replacement for driving in

general but rather another option. So the autopilot should not affect driving skills any more than for instance using public transport or commercial aviation as a passenger”.

Table 5-9: Driving barriers to further developments (n=50).

system	estimated barriers by panel					ranking of barriers	
	SHK	FCAS	LKS	SCAS	AP	all support systems	AP systems
driving behavioural barriers							
counteracting behaviour	2 ¹ (2-4) ²	2 (1-3)	2 (2-3)	2 (2-3)	2 (1-3)	[1] ³	[1]
possible increase workload	4 (4-5)	4 (3-5)	4 (4-5)	4 (3-5)	5 (4-5)	[5]	[5]
possible decrease workload	3 (3-4)	4 (3-5)	3 (3-4)	4 (3-5)	2.5 (2-5)	[4]	[4]
danger of losing skills	4 (3-5)	4 (3-5)	3 (3-5)	4 (3-5)	2 (1-4)	[3]	[2]
lack of driver education	3 (3-4)	3 (2-4)	3 (3-4)	3 (2-4)	3 (2-3)	[2]	[3]

¹group opinion by median: 1=very important barrier; 2=important barrier; 3=moderate-important barrier; 4=unimportant barrier; 5=very unimportant barrier; ²group consensus by interquartile range, i.e. the interval containing the middle 50% of responses (figures printed bold refer to issues on which consensus within the panel was lacking); ³ranking position of barriers by concordance analysis

5.3.4 General impediments

Apart from technical, driving and traffic performance barriers, there is a variety of other issues which might affect the implementation of AVG systems. These were indicated as general barriers in the questionnaire and the respondents were asked to indicate the importance of these barriers for further development. The set of barriers is mentioned in Table 5-10, together with the importance scores from the response group.

Table 5-10 shows that consumer acceptance of the systems is assumed to influence future developments in a significant way. Acceptance will partly depend on the price of the system for drivers and the degree to which drivers consider a certain functionality useful to them. Both issues are considered moderate-important to important barriers for further developments. Given the higher price levels expected for side obstacle avoidance and the autopilot (see section 5.2), costs are logically evaluated to be a stronger barrier to the introduction of these particular systems. In general, the more technically complicated, the higher the consumer costs will be.

Except for speed headway keeping, the panel considered the uncertainty of who will be liable in case of malfunctioning devices to be another serious obstacle to further deployment of systems. As some of the driver's judgements and decisions will be taken over by technology, manufacturers and road-operators could become liable in case of traffic accidents, risking huge claims for damages. Regarding speed headway systems, respondents from America and Japan stated that it is, or expected to be, possible to implement these systems within existing legislation or with minor modifications. In

particular, for those speed headway systems that include brake control, adaptations in legislation are expected to be necessary. The majority of the European respondents argued that these adaptations are likely to be more complicated in Europe, as legislation is not uniform across the different countries. Hence, the implementation of speed headway support with controlling abilities on European roads could take more time. On the other hand, one respondent indicated that, in case the system takes temporary control, he judged legislation to be of moderate-importance, ..“because of concerns about liability exposure of developers and vendors of such systems in the U.S., which has been proposed as a barrier to introduction in this market. Since the U.S. has the highest percentage of normal cruise control and the largest amount of motorway driving, compared to Europe and Japan, one would normally expect it to be the first of the three to have Adaptive Cruise Control on the market, but instead it will be the last of the three..”.

The introduction of the autopilot will most probably require some road adaptations. The panel is highly uncertain about the willingness of public authorities to bear the costs for these adaptations. Finally, international standardisation is considered a difficult issue to overcome only regarding the autopilot. Concordance analyses pointed out that consumer costs and legal issues are evaluated by the panel to be the most dominant obstacles for the set of supporting systems as well as the autopilot (see Appendix, section A.4).

Table 5-10: General barriers to further developments (n=50).

system	estimated barriers by panel					ranking of barriers	
	SHK	FCAS	LKS	SCAS	AP	all support systems	AP
general barriers							
consumer purchase costs	2 ¹ (1-3) ²	2 (1-2)	2 (1-3)	1 (1-3)	1 (1-2)	[1] ³	[1]
consumers perceived utility	3 (2-4)	3 (2-3)	2 (2-3)	2 (2-3)	2 (1-3)	[3]	[5]
public costs road adaptation	5 (4-5)	5 (3-5)	3 (2-4)	4 (3-5)	1 (1-2)	[6]	[4]
liability unclear	3 (1-3)	1(1-3)	2.5 (1-3)	2 (1-3)	1 (1-1)	[2]	[2]
road network applicability	4 (3-5)	4 (3-5)	3 (2-4)	4 (3-5)	1 (1-2)	[5]	[3]
international standardisation	4 (3-5)	3.5 (3-5)	3 (3-4)	4 (3-5)	2 (1-3)	[4]	[6]
consumers privacy	5 (4-5)	5 (4-5)	5 (4-5)	5 (4-5)	4 (3-5)	[7]	[7]

¹group opinion by median: 1=very important barrier; 2=important barrier; 3=moderate-important barrier; 4=unimportant barrier; 5=very unimportant barrier; ²group consensus by interquartile range, i.e. the interval containing the middle 50% of responses (figures printed bold refer to issues on which consensus within the panel was lacking); ³ranking position of barriers by concordance analysis

As for the autopilot the limited road network applicability and the willingness of public authorities to bear the costs of road adaptation are ranked third, respectively fourth. Infrastructure adaptations and privacy of the driver are considered of no substantial importance for the further development of all the supporting systems.

Some respondents stated that the consumer's positive perception of the utility of speed headway support is obvious, given "the positive utility perceived for existing cruise control" and because "this has been demonstrated in focus groups". One respondent mentioned opposite experiences: "empirical data implies that acceptance is not as good as expected for speed headway support". Other respondents considering consumer's perception a barrier, argued that drivers may not be convinced of the high degree of reliability required and "80% of the drivers claim they drive safer than on average, so the need for support seems unimportant to them".

The disagreement within the panel on the willingness of public authorities to bear the costs for infrastructure adaptations as well as the possibly limited road network applicability of system use for the implementation of lane keeping, is related to different assumptions on the technologies required for this system. Some respondents expect this system to be functioning autonomously and "no infrastructure changes will be needed, so it should work on most roads". Others state that "there are excellent markings on today's highways", but "people will buy such systems only if they can be used on many roads". Respondents considering both barriers to be important, argued that road adaptations are needed: "...Optical sensing will require better maintenance of lane markings, magnetic sensing will require magnetic materials in the pavement. Both will add costs which are not currently incurred. This goes against the trend to reduce government spending; because this requires special care to the roads, less roads will be suitable, hence of less utility for some consumers...". Furthermore, "for the system to function properly a very high level of adherence to road design standards is required; such level is presently lacking".

5.4 Conclusions and discussion

The Delphi study points out that the future evolutionary development of driving automation is not as obvious as it is often assumed. Despite the huge research efforts made in the past years, there are still many barriers, which obstruct successful implementation.

In the short term, i.e. before 2005, there exists strong consensus that warning devices for speed headway keeping, lane keeping and obstacle avoidance will become (further) available, next to vehicle-following systems with limited deceleration capabilities. No serious obstacles seem to prevent manufacturers from implementing these systems in the near future, although speed headway support systems with braking capabilities might require some adaptation of existing traffic law rules. Lane deviation warning systems could need more infrastructure maintenance than on average or even some roadway instrumentation in order to operate appropriately under all conditions.

Next, systems which assist the driver to prevent collisions with moving or stationary front vehicles are likely to become available between 2005 and 2010. This also yields lane keeping control systems. The introduction of more advanced systems which taking adequate, temporary control of the vehicle in case of dangerous situations with more general obstacles, is still considered uncertain. Electronic control devices for side obstacle collision avoidance are not expected to become available before 2010. In general, the

market entrances and penetration of supportive systems will, next to consumer acceptance, largely depend on future technological progress of systems' operating capabilities and transparency concerning liability issues.

Overall, these supportive systems are all expected initially to be of use within motorway environments only, and to be adopted by professional drivers and fleet-operators. The study further pointed out that the contribution of most of these support systems to road capacity gains and reduction of environmental impacts are (highly) uncertain. Moreover, safety improvements may be achieved but these are strictly limited to those driving situations the system is designed for and these could easily be countermeasured by more risky driving behaviour. Furthermore, for each type of support various systems could become available with different operating characteristics. It is unclear how this diversity will affect total traffic performances.

Most uncertain seems the implementation of the autopilot. The feasibility of various technical as well as non-technical conditions under which the implementation of this new transport mode can be achieved is considered highly uncertain. This, in turn, undermines the validity of the often claimed huge traffic performance improvements claimed by this system, based on highly restricted field experiments, assuming no malfunctioning technologies and no mix with manually operated vehicles. Next, there is a possibility that these benefits could be restricted to the dedicated lanes within the road network only, whereas the non-automated part could well be disadvantaged, both in safety and capacity.

The technology driven nature of the development yields a body of research that seems to put less emphasis on the impacts of the systems with respect to the performance of the transport system as a whole. This is related to a fundamental belief that this type of systems is always good for improving driver as well as traffic flow behaviour. However, the main conclusion of this study is that despite the enormous financial and research efforts in this field, there are still many uncertainties in this respect.

This requires a stronger focus on successes of implementation in the short term, i.e. what can be reached in the near future? It implies a shift in attention from systems fully automating the total vehicle driving task to systems supporting part of the driving task by information or limited control.

As indicated in section 2.4, the next step is to research the likeliness of handling the identified barriers to implementation in time. It implies an answer to the question whether it is plausible that the related decisions and/or actions will be taken in time. In terms of research, it requires the identification of the parties being involved in those decisions and actions. Moreover, the willingness and possibility of those parties to act, has to be analysed.

For the near future, i.e. up to 2010, the Delphi study points out that the implementation of the first AVG systems is not an exclusive matter of R&D on technologies anymore. After all, systems supporting the driver on speed headway keeping, lane keeping and collision avoidance (between vehicles) are already available or are expected to become available in the near future. Consequently, the focus in relation to implementation is shifting to market opportunities for these first systems. Therefore, it is important to gain insight into the desires of the market, the willingness to purchase systems, the potential use

of systems, etc. In general, the experts expect 'motorway' drivers (car, bus and truck) as well as related fleet-operators to be the first markets for which systems will become available. Hence, the next step is to gain more insight into the preferences these groups have when being confronted with these systems. This will be central in the remaining chapters of this thesis.

Chapter 6.

Exploring preferences for early AVG based on conjoint analysis

6.1 Introduction

In the previous chapter it was concluded that future consumer behaviour will significantly influence the implementation of early AVG systems. These systems support speed headway keeping, lane keeping as well as front and side collision avoidance between vehicles. Given the aim of our research and the adopted methodology, we need more in-depth knowledge about consumer behaviour regarding these systems. Since this behaviour is not measurable in a direct way (the systems are not available yet), an indirect way has to be followed. A well-accepted approach in this prospect is measuring preferences, based on the assumption that there exists a direct relationship between preferences and overt behaviour. Consequently, the next step in research is to explore the preference behaviour of consumers regarding these systems as well as identifying possible differences between groups of consumers. In particular, we are interested in the relationship between the features of systems and the preferences of consumers.

In this chapter an approach is specified to model these preferences. In section 6.2 an overview is given of relevant studies performed in the past, indicating that no appropriate approaches can be found. Hence, an approach being used in other fields of research is adopted, known as conjoint analysis. The concept underlying conjoint analysis is presented in section 6.3 and the set-up of a conjoint experiment in general is presented in section 6.4. Next, the design of the experiment for this study is presented in section 6.5. In section 6.6 the set-up of the questionnaire is given which has been used to determine the preferences of consumers. Finally, in section 6.7, some conclusions are drawn with respect to the elaborated approach.

6.2 An overview of studies performed on AVG preferences

Different researchers have studied the preferences of consumers regarding AVG systems. We will briefly elaborate on some of these studies in order to discuss the approach used and results obtained in these studies.

Lathrop & Chen (1997) studied a.o. the attitudes of private users and non-users, fleet-operators, vehicle- and electronics industries, insurance companies and public authorities concerning AHS. For some groups (private users/non-users, vehicle industries and public decision makers) the concerns, expected benefits and impacts of different AHS options were elicited in focus group meetings. For each group these characteristics were rated, according to their specific preferences. The rating for the user group resulted in the following list of characteristics (in decreasing order of importance): (1) reduction of accidents; (2) travel time savings; (3) usability of AHS services on non-AHS roads; (4) system integrity; (5) travel time predictability; (6) vehicle operating cost; (7) access/egress to AHS in the regional freeway network; (8) vehicle capital costs; (9) aesthetics; (10) environmental impacts and (11) the possibilities of drivers to override automatic control.

The study has limited value, since it only considered preferences regarding fully automated driving and did not consider less forms of vehicle driving automation. Furthermore, as respondents have rated different features of AHS separately, no insight is obtained onto how these ratings have to be combined into an overall preference for AHS. Finally, the focus groups consisted of representatives of stakeholders regarding AHS, and not of the users themselves. As such, the opinions might be biased and might not represent the preferences of the future users of AHS sufficiently.

Horowitz (1996) surveyed user needs and opinions about speed headway support, collision warning, automatic steering and the Automated Highway Systems (AHS), using the Internet. Respondents were invited to rate the new technologies on a like/dislike scale. It appeared that "... A large proportion of respondents have needs for improving the freeway driving experience in terms of driving stress, environment, congestion, and safety. Furthermore, most respondents believe in the potential of technologies, including AHS, to satisfy needs. Necessary conditions for public acceptance of AHS are high levels of system safety, reliability, and benefit/cost ratio, and minimum driving-induced stress. Collision Warning Systems may satisfy drivers' needs for safety if human factors' issues are satisfactorily solved...".

As the technologies were described in terms of their general functionality, no insight is obtained into the relationship between systems features and overall preferences. Furthermore, no costs of systems were included. This characteristic is likely to influence future preference behaviour in an important way. Finally, the Internet is not a common medium (yet) to the general driving population, but it is likely to be used by early adopters of technologies. Hence, respondents who are generally positive to innovative technologies might bias the sample and as such their opinions regarding AVG systems might be optimistic. A similar bias has been found by Gobits (1999), in a study on the use of the Internet for providing travel information.

A study on initial reactions of new vehicle purchasers to several crash avoidance concepts, using focus group meetings, pointed out that collision avoidance systems were viewed more favourable than speed headway support (Kemp et al, 1998). Regarding collision avoidance systems, backup warning devices were most popular, followed by side obstacle collision avoidance. Less popular, but still positively evaluated, were front collision detection and road departure warning.

In this study no data has been collected as to the influence of systems costs regarding the overall preferences. Furthermore, the reported results were only qualitative and did not give any information on the degree of preferences. Next, as only the opinions of new vehicle purchasers have been collected, the results are only limited representative of the total vehicle driving population. In particular, the preferences of first-user groups like company car drivers and commercial heavy-vehicle drivers, being often not responsible for vehicle purchasing, have not been researched in this study.

A more representative sample has been used within a study performed by Hoedemaeker (1999). In this study the opinions of Dutch car drivers regarding speed headway support or adaptive cruise control, collision warning, collision avoidance and automated highways are studied by means of a post survey. Respondents were invited a.o. to indicate pros and cons of the systems according to their opinion. Some results are summarised in Table 6-1, a '+' indicating a positive characteristic of a system and a '-' indicating a negative characteristic of a system.

Again, as in the previous study, no costs were included in this study and no insight is obtained into to what degree system features are influencing the respondents' opinion.

Table 6-1: User opinions on some AVG systems

collision warning	collision avoidance	adaptive cruise control	automated highway
+ safety	+ safety	+ safety	+ throughput
+ changes behaviour	+ risk collision	+ throughput	+ energy reduction
- alertness	- intervention	- intervention	- intervention
- irritating	- dangerous	- sudden brake	- driving pleasure

Source: Hoedemaeker (1999)

Sayer et al (1995) performed a study which considers the costs of a system. In this study drivers' reactions are questioned on a speed headway support system with limited controlling capacity (throttle control). Thirty-six drivers were questioned on comfort, safety, ease of use and estimated value of a speed headway support system after having driven for one hour with a prototype in a real-world traffic environment. Although the participants were rather positive on speed headway support, they appeared not to be very willing to pay much for the system: on average, participants were willing to pay \$200 to upgrade their conventional cruise control system to a speed headway support system.

In this experiment only speed headway support has been evaluated and no other types of support. In general, by using real-world experiments one can often evaluate a few prototypes. Furthermore, the number of respondents was low. Twenty-four drivers were

willing to participate in the survey. Hence, the transferability of the results to the total population might be limited.

Real-world experiments with larger groups have also been performed. Becker (1994) reports the following conclusions on user acceptance of different types of adaptive cruise control, based on different real traffic experiments carried out by 200 test drivers in combination with questionnaires. In general, the speed headway support was perceived as a comfort-oriented and safety-enhancing driver support system. It implies a large amount of user acceptance, in particular for control systems with automatic decelerating capabilities. Systems giving distance information or warnings, enjoyed only moderate acceptance. The willingness of participants to buy a system was measured too. Two hundred Subjects were interviewed at the vehicle test tracks: 80% of the subjects would probably buy a controlling system in their new vehicle at a price level of DM 1500,-. At a price level of 2500 DM this percentage logically dropped, but still 40% would probably buy a controlling system in their new vehicle. Unfortunately, only speed headway support was considered in this study and no other types of driving support.

Tribe et al. (1995) report driver preferences for different types of driving support. This experiment concerned Intelligent Driver Support (IDS), a system that allows for different types of support: adaptive cruise control, collision avoidance, and lane keeping support. A group of twelve drivers was invited to drive with the IDS system on public roads. Next, drivers assessed the relative importance of each type of support, in order to enable the researchers to assess the drivers' preferences.

Adaptive cruise control was favoured, followed by lane keeping support. Collision avoidance by emergency braking, respectively a haptic pedal was less popular. No findings have been reported on the costs. Furthermore, only twelve subjects were included in this study. As such, the results are likely to be not representative for the total car driving population.

In summary, several approaches have been used to assess user preferences regarding AVG including questionnaires, interviews, focus group meetings, etc., sometimes in combination with driving simulator experiments or road experiments. Although these studies are valuable, they all have serious limitations.

None of the researchers explicitly discuss the reasons to choose between different possible approaches as most studies lack some theoretical background/view on preference behaviour. Often, approaches are chosen being based on practical considerations, which can be applied straightforward.

It further appears that empirical results for consumer preferences regarding AVG systems show different, unexplained results. Furthermore, as most studies bear a qualitative character, the degree to which users will adopt these systems remains rather unclear.

Hence, the overview of different studies indicated that the relation between different driver support features and the preferences of consumers to buy and use these systems is still subject of further empirical research (Shladover, 1999). The question remains how to improve insight into this relationship. The studies discussed do not offer us interesting conceptual and methodological insights with respect to the specific purposes of our

research. For that reason, we are forced to adopt views on individual decision-making processes as developed in other fields of research. In particular, the theories and approaches used in the so-called behaviouristic school open an interesting avenue for our research (Marchau & Van der Heijden, 1997). In the next section these theories and approaches are specified.

6.3 A conceptual view on individuals preference and choice behaviour

Inspired by the theory of choice behaviour in spatial and marketing research (e.g. Timmermans 1982; Louviere, 1988) we postulate that preference and choice behaviour is the result of an individuals' cognitive behavioural decision-making process. This behaviour is based on the subjective perception and evaluation of choice alternatives in terms of their physical, functional and socio-economic attributes. This then results in an individual preference structure that determines the ultimate choice of an alternative. In particular, we assume the following steps underlying an individual's decision process (e.g. Timmermans, 1982) (see Figure 6-1):

1. a set of objective alternatives exists of which an individual can choose from;
2. each individual overlooks an individual choice set of alternatives being a subset of the set of objective alternatives (subjective filtering);
3. individuals perceive the alternatives in subsets as bundles of attributes with specific values. These attributes relate to individual criteria for choice;

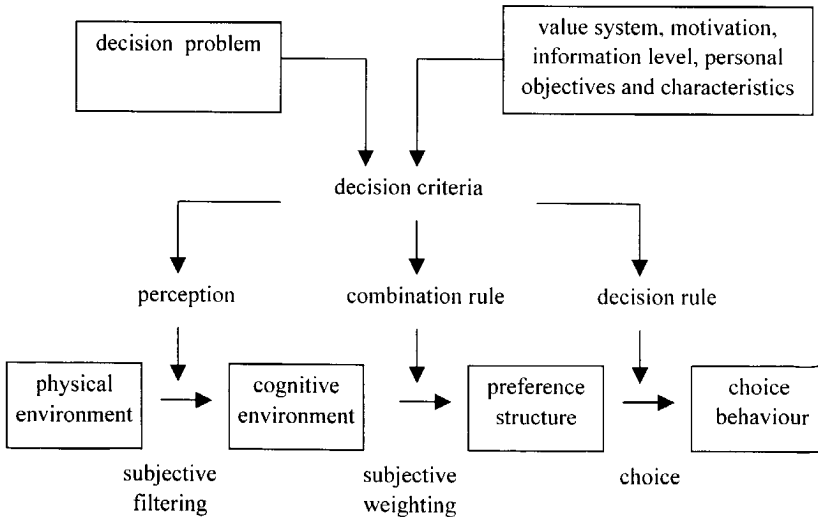


Figure 6-1: A conceptual view on individual decision-making

4. each individual derives a certain utility from each attribute-level, the so-called part-worth utility;
5. individuals combine part-worth utilities of separate attributes into an overall utility or preference for each alternative, according to some combination rule;
6. individuals choose an alternative based on a decision rule applied to the overall utilities.

These assumptions can be modelled mathematically in the following way (e.g. Van der Heijden, 1986). By the first assumption, there exists a set S of n objective alternatives with

$$S := \{\text{alternative } 1, \dots, \text{alternative } n\} \quad (n \geq 2) \quad (6.1)$$

Suppose for individuals the subscript i is adopted, for alternatives the subscript j and for attributes the subscript k . The second assumption is that there exist individual-specific choice sets S_i of m alternatives, which is a subset of S :

$$S_i := \{\text{alternative } 1, \dots, \text{alternative } m\} \quad (2 \leq m \leq n) \quad (6.2)$$

The third assumption is that each alternative j can be described by means of a vector X_j of attribute-levels X_{jk} , with X_{jk} being the objective value of the k -th attribute of alternative j :

$$X := [X_{jk}] \quad (6.3)$$

By the fourth assumption, each individual i derives a certain (part-worth) utility V_{ijk} from each attribute-level k from alternative j . This part-worth utility is some function f_i of X_{jk} :

$$V_{ijk} := f_i(X_{jk}) \quad (6.4)$$

By the fifth assumption, it is stated that each actor combines part-worth utilities, V_{ijk} , of separate attributes into one overall utility, V_{ij} , for each alternative j . This combination rule can be defined by some function f^* :

$$V_{ij} := f^*(V_{ijk}) = f^*(f_i(X_{jk})) \quad (6.5)$$

The subjective ordering of alternatives according to the individual's overall utility is referred to as the preference structure or preference function of the individual. This function is the base for making a choice. The sixth assumption states that individuals choose an alternative based on some decision rule which is defined by some function, f_i , of the overall utilities:

$$P(j \mid j \in S_i) = f_i(V_{ij}) \quad (6.6)$$

The simplest option is to assume a deterministic decision rule for f_i , which states that individuals invariably choose the alternative with the highest overall utility (Van der Heijden, 1986). Other options involve probabilistic rules, assuming that an individual's overall utility is composed of the fixed component (V_{ij}) and a random component (e_{ij}), induced by for instance measurement error. The overall utility (U_{ij}) now becomes

$$U_{ij} := V_{ij} + e_{ij} \quad (6.7)$$

If again, it is assumed that the alternative with the highest utility is chosen, the probability P_{ij} , that an individual i prefers alternative j to alternative j' is then given by

$$\begin{aligned} P_{ij} &= P(U_{ij} > U_{ij'}) \\ &= P(V_{ij} + e_{ij} > V_{ij'} + e_{ij'}) \\ &= P(V_{ij} - V_{ij'} > e_{ij'} - e_{ij}) \quad \forall j \neq j' \end{aligned} \quad (6.8)$$

Now, different choice models can be derived, depending on the assumptions made for the distribution of error. For instance, if it is assumed that the random utility components are identically and independently double exponentially distributed, the multinomial logit model can be deduced.

$$P_{ij} := \frac{\exp(V_{ij})}{\sum_{j'} \exp(V_{ij'})} \quad \forall j, j' \in S_i \quad (6.9)$$

Evidently, the model encompassing these mathematical specifications has to be further operationalised in order to be able to predict preferences of individuals regarding the different AVG systems under consideration. This operationalisation heavily depends on the choice of the procedure by which part-worth utilities as well as the influence of attributes on the overall utility are determined (Timmermans, 1984).

In general, two options are possible in this context, that is a compositional approach and a decompositional approach. A compositional approach involves that several attributes underlying preferences are identified and individuals are asked to indicate preferences and choices for each attribute directly. Consider for instance a distance keeping support system, which supports the driver in keeping a safe following distance to the preceding vehicle. Drivers could be asked to evaluate different levels of intervention, different levels for time headway, different prices, etc. Next, they could be asked to indicate the importance of each of these attributes. The evaluations of attribute-levels and weights of different attributes can now be combined to come to an overall utility, assuming some ad hoc combination rule. The overall utility is thus composed by the respondents' explicitly measured preferences and importances for separate attributes. However, this approach has shown serious limitations in terms of predicting overall preference and choice behaviour. Individuals are

likely to overestimate the importance of unimportant attributes, if they are not forced to make trade-offs between the different attributes of an alternative (e.g. Oppewal, 1995).

These disadvantages are avoided by the decompositional measurement approach. Here, individuals have to indicate their overall preference for a hypothetical alternative (concept or product) described in terms of a set of levels of pre-specified attributes. Individuals are hereby explicitly forced to make trade-offs among attributes. The overall preference is decomposed into the weights these individuals attach to separate attribute-levels in creating their overall evaluation of the alternative. This approach is also known as conjoint analysis.

There are some basic advantages of the conjoint analysis approach in relation to comparable traditional methods in which individuals are asked to judge attributes separately, including (Timmermans, Molin & Van Noortwijk, 1994):

- a coherent view on evaluation of alternatives and decision making is provided;
- this approach has proven to be well performing in terms of predicting preference and choice behaviour in marketing and service industries;
- a well-developed set of research tools is available for the operationalisation of this conceptual model.

Next to these advantages, some limitations of conjoint analysis should be taken into account. There exists some uncertainty about the relationship between preferences and choices made by individuals in experiments and their real-world preference and choice behaviour. Although research has been conducted to overcome these pitfalls (e.g. Timmermans, 1984), attention should be paid to these notions. Another disadvantage involves that so far, to our knowledge, the approach has mostly been applied in the context of preferences and choices regarding well-known products and services among the individuals questioned. In our research, however, it is unlikely that individuals will be familiar with the systems questioned, due to the innovative character of AVG. Hence, it is uncertain if individuals will be able to understand and evaluate the systems properly.

Nevertheless, conjoint modelling probably provides an attractive approach for ex ante explorations of consumer preference and choice behaviour regarding early AVG systems. In particular the theoretical foundations, advanced error theory and flexibility for developing and using advanced research tools make a conjoint approach highly attractive (Molin, 1999). The potential limitations of a conjoint approach should be taken into account when setting up a conjoint experiment. This set-up will be discussed in the next section.

6.4 The set-up of conjoint experiments

The following steps are usually taken when setting up and analysing a conjoint experiment (Vriens, 1995; Molin, 1999):

- a selection of salient attributes;
- the determination of relevant attribute-levels;
- a selection of an appropriate method for combining attribute-levels into profiles;
- the choice of a measurement task;
- a choice of a method for estimating utility or preference functions;
- the simulation of preferences and choices.

For each step different strategies are possible, being related to different assumptions, criteria and specific needs of the researcher. This section discusses the strategies that are possible and the criteria to choose one particular strategy.

6.4.1 The selection of salient attributes

The first step in designing a conjoint experiment involves the selection of the most salient attributes that influence the preference and choice behaviour of interest. The identification of all attributes (and relevant levels) which influence preference and choice behaviour is essential. Ignorance of important attributes logically generates invalid trade-offs. Different approaches have been applied to identify determinant attributes, including (Louviere, 1988): (1) using the results of previous research done in the same area; (2) repertory grid methods, implying that respondents are repeatedly shown groups of three products and asked to specify in which way two products are alike and thereby different from the third one; (3) factor listing, by which respondents indicate reasons for choosing a specific alternative; (4) focus group interviews, in which user groups are asked to discuss together the reasons why they buy a product, and (5) rating procedures, by which respondents are invited to indicate the relative importance of a set of a priori defined factors. Next to the characteristics of an alternative it is assumed to influence preference and choice behaviour, those attributes that are of particular interest for the researcher can be added (Oppewal & Timmermans, 1992).

In general, for the identification and definition of the most salient attributes the following criteria to product or service characteristics are usually considered (Louviere, 1988; Louviere & Timmermans, 1990): (a) ignorance of specifying attributes which are only relevant for some individuals; (b) nonredundancy; (c) actionable and interesting for decision makers, and (d) clearly and meaningfully formulated for respondents.

6.4.2 The determination of relevant attribute-levels

After the attributes have been selected, the next step is to identify the relevant attribute-levels. This implies the choices of an appropriate range and number of levels. In general, the number of attributes and attribute-levels is traded-off against the number of profiles which is expected individuals can properly evaluate in practice. It is clear that number of profiles increases rapidly as the number of attributes and levels increases. Usually, the number of levels tends to be limited to 4 (Vriens, 1995). It is further recommendable to try to equalise the number of levels across attributes, as research has pointed out that the relative importance of an attribute increases as the number of levels increases (e.g. Hair et al, 1998).

Further choices are related to the nature of the specific attribute, i.e. whether the attribute can have only specific, categorical values or whether the attribute can have all kinds of levels on a continuous scale.

The range of attribute-levels for categorical attributes is often fixed by, for instance, technical, market or other constraints. Furthermore, all relevant levels have to be included for both the individuals and the decision maker.

Regarding continuous attributes, the range of levels is related to those values that are assumed to represent plausible, future alternatives. The number of levels is dependent on the shape of the utility function assumed. If a linear relationship is assumed a minimum of two levels is considered; if a quadratic relationship is assumed a minimum of three levels is considered, and if a cubic relationship is assumed a minimum of four levels is considered.

6.4.3 The selection of a method for combining attribute-levels into profiles

After the selection of attributes and their levels, now these levels have to be combined in order to generate profiles that can be evaluated by the respondents. Statistical design principles are used in order to create profiles, as this enables an efficient and unbiased estimation of the preference structure (Molin et al, 1997).

An approach is to construct full profiles, which are combinations of levels of all selected attributes. The number and composition of full profiles depends on the choice of the experimental design (Molin, 1999). In turn, the choice of an experimental design depends on the combination rule assumed, i.e. how individuals combine part-worth utilities into overall utilities.

It has been shown, based on empirical evidence, that simple polynomial models approximate the unknown decision process reasonably well (Louviere, 1988). In particular, it is often assumed that individuals simply add their part-worth utilities to arrive at overall utilities. The models which can be distinguished under this assumption include:

- main-effects or linear model: the overall utility is the sum of the separate part-worth utilities, assuming that the part-worth utility of an attribute-level is independent of the levels of other attributes. No interactions are taken into account. This model takes the general form of:

$$V_j = c_0 + \sum_k c_k V_{jk} + e_j \quad (6.10)$$

with:

V_j = utility of alternative j

V_{jk} = part-worth utility for attribute-level k from alternative j

c_0 = constant, indicating a basic preference

c_k = scaling constants

e_j = error term

- interaction-effects or multilinear model: the overall utility is the sum of separate part-worth utilities together with the sum of products of part-worth utilities, thus that the part-worth utility of an attribute-level is not independent of the levels of other attributes. Here it is assumed that there are interaction effects between different levels of included attributes. For instance, in case of two 2-level attributes the multilinear model becomes:

$$V_j = c_0 + c_1 V_{j1} + c_2 V_{j2} + c_3 V_{j3} + c_4 V_{j1} V_{j2} + c_5 V_{j1} V_{j3} + c_6 V_{j2} V_{j3} + c_7 V_{j1} V_{j2} V_{j3} + e_j \quad (6.11)$$

with:

V_j = utility of alternative j

$V_{j.}$ = part-worth utility for attribute-levels 1 to 3 from alternative j

c_0 = constant, indicating a basic preference

c_1, \dots, c_7 = scaling constants

e_j = error term

The choice of an appropriate experimental design involves a trade-off, the researcher has to make, between the possibility to estimate and test interaction effects against the requirement to reduce the number of profiles in order to avoid fatigueness and boredom among respondents as well as to reduce the complexity and expense of the data collection effort. For a full-factorial design, which involves all possible combinations of selected attribute-levels, it is possible to estimate all possible interaction effects. It might be clear that the number of profiles rapidly increases as the number of attributes and/or attribute-levels increases and as such the number of profiles becomes too large to be properly evaluated by respondents

By assuming some interaction-effects equal to zero, it is allowed to create a fractional factorial design. For fractional designs, the number of profiles to be evaluated is smaller as compared to full factorial designs. In general, the interaction effects between three or more attributes do not contribute significantly to overall utility (Steenkamp, 1985). Furthermore, it is difficult to interpret these interaction effects. The interaction effects between two attributes, so-called first-order interaction-effects, can sometimes be of interest.

However, no interaction effects between attributes are often assumed, which results in the main-effect model (Hensher, 1994). This model is often used in practice, as it

minimises the number of profiles to be assessed, and it has proven to have a reasonable predictive validity (Louviere, 1988).

Several so-called 'main-effects' designs are possible. An important characteristic of designs in general is that they are orthogonal. An orthogonal design is a design in which the levels of different attributes across profiles are not correlated. Such designs assure that an estimate of the effect of one attribute-level is unaffected by the estimate of the effects other attribute-levels and provide the lowest number of profiles to be evaluated by respondents in order to estimate the main-effects model (Huber, 1987). As the choice of a so-called orthogonal 'main-effects' design is rather complicated, basic plans have been developed for which various orthogonal main-effects designs can be constructed (Adelman, 1962; Steenkamp, 1985).

6.4.4 The choice of a measurement task

As the profiles have been constructed, they have to be evaluated by the respondents. Generally, respondents are invited to indicate their preferences regarding the various profiles. This can be done in different ways including: (1) ranking the profiles from most preferred to least preferred profile, (2) rating of profiles on a certain scale, and (3) choosing the preferred profile between two or more alternatives. The task of rating and ranking alternatives is addressed as a stated preference task, whereas choosing alternatives is called a stated choice task. In general, preference and choice experiments each have its advantages and disadvantages.

An advantage of preference tasks is that more information is given by each specific measurement as compared to choice tasks. By choice tasks information is collected whether an individual does or does not prefer alternatives, whereas in case of preference tasks information is collected regarding the degree of the preference regarding alternatives. Hence, preference measurements give more information on the preference structure of subjects and by ranking tasks (ordinal level) and rating tasks (interval level). Hence, the typical preference structure at desaggregate level can more easily be estimated. As choice tasks are of nominal level, i.e. choose or not choose an alternative, only model estimation at aggregate level can usually be estimated. Another advantage of preference tasks is that they are more easily to construct as choice tasks require an additional step in which the profiles have to be placed in choice sets out of which respondents are invited to choose the most preferred profile.

By preference tasks no choices are measured, no direct, empirical results are obtained on the choice behaviour of respondents. Some ad hoc rule underlying the choice of an alternative has to be assumed, based on the preferences measured. For instance, it is often assumed that the alternative with the highest utility will be chosen. Stated preference tasks is that these tasks might be considered rather unrealistic to respondents as people are more familiar with choosing between alternatives. Hence, stated preference tasks might give less valid results regarding choice behaviour. Choice tasks might approximate real-world decision behaviour in a better way and the results of stated choice experiments might

enable a more valid assessment of the future market share of an alternative, using for instance multinomial logit models.

6.4.5 The choice of a method for estimating preference models

Once the preferences of respondents have been measured, an estimation procedure has to be applied to determine the part-worth utilities or parameters of the multiattribute preference model. Statistical estimation procedures are commonly used in this context. Which particular technique should be followed, depends on the type of data collected by the measurement task:

- in case the dependent variable is measured on ordinal level (ranking), nonmetric procedures like monotone regression or linear programming can be used. It should be noted that, in general, nonmetric estimation procedures do not give better results than metric procedures (Vriens, 1995);
- in case data is collected by rating the different profiles on a scale which can assumed to be of interval level, metric procedures like ordinary least square (OLS) regression techniques can be used. The dependent variable is given by the profile scores provided by the respondents and the attribute-levels represent the independent variables;
- in case data is collected by a choice task, in which respondents indicate their choice between two or more profiles, one usually uses maximum likelihood techniques to estimate the parameters of the choice model.

In order to include categorical or nonmetrical attributes into the analysis, the attribute-levels have to be coded. Such coding involves the transformation of nonmetric attribute-levels into indicator variables. An indicator variable is a dichotomous variable that represents one category of the original, nonmetric attribute (Hair et al, 1998). Different coding strategies are possible but the coding strategy itself does not affect the overall results. The resulting values only require a proper interpretation. For instance, effect coding can be applied. In case of effect coding, the attribute-levels are coded 1 on their corresponding indicator variable and one attribute-level is coded -1 on all indicator variables (see Table 6-2). It is clear that, in general, each L -level attribute is represented by $L-1$ indicator variables. Thus, in case of a three-level attribute, two parameters are estimated: β_1 and β_2 . It means that the part-worth utility of each attribute-level is now calculated by multiplying the β_i with its code and adding the results across the coded columns. For instance, the part-worth utility of the first attribute-level is $\beta_1 * 1 + \beta_2 * 0 = \beta_1$ and the part-worth utility of the second attribute-level is $\beta_1 * 0 + \beta_2 * 1 = \beta_2$. The part-worth utility of the third attribute-level is $\beta_1 * (-1) + \beta_2 * (-1) = -(\beta_1 + \beta_2)$. By definition, in using effect coding the sum of part-worth utilities of an attribute is zero.

Table 6-2: Effect coding for a three-level attribute

attribute-level	effect coding		derived part-worth utility
	first indicator variable	second indicator variable	
0	1	0	β_1
1	0	1	β_2
2	-1	-1	$-(\beta_1 + \beta_2)$
estimated parameters:	β_1	β_2	

6.4.6 The simulation of preferences and choices

After the specification of the model, it is now possible to simulate preferences and choices for all possible combinations of attribute-levels. In case, for instance, a preference model has been estimated, the overall preference for each profile of interest is calculated by filling in the related part-worth utilities into the estimated model. Furthermore for continuous attributes, part-worth utilities of intermediate attribute-levels can be derived by interpolation. This allows the simulation of preferences for all profiles, which can be constructed within the range of (continuous) attribute-levels. Finally, choice behaviour between profiles can be simulated by assuming some decision rule. For instance, it could be assumed that individuals, when confronted with different profiles, will choose the profile with the highest utility. Given for instance two different profiles, the number of respondents that will choose each profile can be determined by calculating, for each respondent, the preference scores for each profile and identify which profile will be chosen, assuming that the profile with the highest score will be chosen. This decision rule is however rather basic and more sophisticated decision-rules have been presented, which appear more robust descriptions of real-world choice patterns (Timmermans & Van der Heijden, 1984).

In general, one should take care when predicting choice behaviour based on preference models, as some relationship between overall preferences and choices is assumed and can not be tested. In case choices have been measured directly among individuals, the choice probabilities can be determined without such additional assumption on the decision rule.

6.5 Designing the conjoint experiment regarding early AVG systems

In the previous section the methodological steps to be followed for the set-up of conjoint experiment has been presented as well as the possible options within each step has been discussed. In this section, the specific design of the conjoint experiment for this study is presented. Each of the steps as described above will be handled and operationalised.

6.5.1 Determinant attributes of early AVG systems

The first step involves the selection of determinant attributes. Given the rather futuristic character of driver support technologies the results of other studies have been used to identify an initial list of relevant characteristics, which are assumed to influence preference and choice behaviour. The other possible approaches to select attributes require that potential consumers have a clear understanding of the technologies which is unlikely, given the fact that these systems are coming to the market these days. Hence, as most consumers are probably unacquainted with these systems, one can further not expect that they will be able to indicate the characteristics of systems, which might influence their preference and choice behaviour.

In section 6.2 some of these characteristics have been given. Initially, the following list of system characteristics is considered to determine, in theory, preference and choice behaviour (e.g. Turrentine et al, 1991; Horan & Barnes, 1995; Fancher et al, 1995; Levine & Underwood, 1996):

- *technical characteristics*: characteristics related to the (i) system operating functionality; (ii) system-technical integrity, and (iii) usability or applicability of the system;
- *cost-benefit characteristics*: characteristics related to the impacts of the system on (i) traffic safety; (ii) traffic efficiency; (iii) driving convenience; (iv) environment, and (vi) costs.

The next step is to operationalise these theoretical system characteristics to clear, measurable attributes, which discriminate alternatives sufficiently from a consumer's point of view. Based on the findings in the Delphi study, the technical and cost-benefit characteristics above-mentioned can be operationalised in order to meet the criteria as presented in subsection 6.4.1. As for *technical characteristics* this comprehends the following specifications:

- The characteristics related to the system operating functionality are based on the functionality of the systems expected to become (further) available before 2010, i.e. speed headway support, lane keeping and front and side collision avoidance (between vehicles). They will be specified as the attributes *distance keeping support*, *lane keeping support* and *lane changing support*. Both speed headway support and front vehicle collision avoidance are represented by the same attribute, namely distance keeping, in order to avoid confusion among respondents.
- The characteristics related to the system integrity are the technical reliability and the accuracy of a system. Although these characteristics are, by the experts participating to the Delphi study, considered serious barriers to further implementation, it is, for commercial reasons, unlikely that systems will be marketed when there is a

probability of malfunction technology. Therefore, no attribute related to system integrity is included.

- The applicability of a system refers to the traffic conditions under which the systems can be used. Motorways are expected to be the most appropriate roads for initial use of the systems considered in this study (see section 5.2). No other options are assumed in the short term. Therefore the applicability of a system is not included and all systems will be presented for motorway-use only.

Regarding the *cost-benefit characteristics*, the following specifications have been made:

- In general, it is expected that the systems considered in this study will improve driving safety and driving convenience (see Table 5-7). However, it is difficult to operationalise these characteristics into clear/meaningful attributes which are perceived unambiguously by respondents. Furthermore, safety and comfort refer more to perceptions of systems characteristics. These perceived contributions of the systems to the respondents' driving comfort and driving safety are, however, of interest. Therefore, perceptions in this respect will be asked explicitly.
- Traffic efficiency refers to the possible changes a system can induce on traffic throughput. To consumers possible changes of travel time as well as the predictability of the trip duration represent traffic efficiency. The predictability of a trip duration is initially not expected to be affected by the alternatives considered and is consequently not included. Traffic efficiency will be specified by the attribute travel time.
- For environmental performance, the impact of a system on fuel consumption performance is of basic interest. The influence of systems on emissions could also be added but this is directly related to the possible changes in fuel consumption (Browand et al, 1997). Therefore, emission performance is not included as a separate attribute and environmental performance will be represented by the attribute fuel performance.
- Regarding the cost characteristics of a system, a distinction can be made between capital costs and operating costs. Capital costs refer to the costs for consumers in case of buying a system. These costs will be referred to the attribute price of the system to the consumer. Operating costs refer to the impacts a system might have on the costs of vehicle operation. These costs are already partially represented by the attribute fuel consumption. The maintenance of technologies on a regular base may induce some additional operating costs. These costs will, however, considered to be negligible compared to the overall maintenance costs. Vehicle operating costs are consequently not included as a separate attribute in this study.

Summarising, the following attributes underlying preference behaviour of consumers for early AVG systems result:

- *technical attributes*: distance keeping support, lane keeping support and lane

changing support;

- *cost-benefit attributes*: price (purchase costs), travel time and fuel consumption performance.

6.5.2 Relevant attribute-levels for early AVG systems

Given the attributes as presented above, the next step involves the specification of relevant attribute-levels. The technical attributes as defined in this study can only have categorical values and the selection of appropriate attribute-levels can be based rather straightforward on the results of the Delphi study.

Regarding the attribute *distance keeping support*, the following levels are expected to become available before 2010 (see Table 5-4): 'distance warning' (front vehicle collision warning), 'throttle control' (limited speed control in reaction to preceding vehicle) and 'throttle and brake control' (autobrake or front vehicle collision avoidance). For *lane keeping support*, the following levels are expected to become available before 2010: 'road departure warning' and 'lane keeping steering support'. The level 'none' is added as, in general, distance keeping support is expected to become earlier available as lane keeping (see Table 5-4). Regarding the attribute *lane changing support*, only the level 'blind spot warning' is expected to become available for the near future. Again, the attribute-level 'none' is added, for the same reason as this level was included for the attribute lane keeping. Although the level 'lane change steering support' is expected to be introduced later on, after 2010, it is included for methodological reasons, i.e. to keep the number of levels equal across attributes.

For the cost-benefit attributes the specification of attribute-levels requires additional information, as these levels cannot be derived directly from the results of the Delphi study. The levels for these attributes are partially based on estimates from other studies. Regarding the attribute *price* of separate system functions, the experts estimated warning devices to become available for a price between \$500 and \$1000 and intervening devices for a price between \$1000 and \$1500 (see Table 5-5). The prices of systems which combine different system operating functionalities (front and side obstacle detection) start around \$2000 (Apogee Research Inc., 1997). In this study it is assumed that combinations of functionalities will be cheaper than the sum of single functionalities. Consequently, the attribute-levels '\$500', '\$1500' and '\$2500' are considered realistic.

Furthermore, the experts indicated that the direction of the impacts on travel time and fuel performance is rather uncertain. Therefore, positive as well as negative changes are considered relevant attribute-levels for both attributes.

It is assumed that initial lateral support systems will have no serious impact on *travel time* performance. These systems are safety devices. This is not the case for distance keeping support. Although serious research efforts have been conducted on the analysis of the influence of longitudinal support systems on traffic flow improvements, the possible increase in road capacity due to these systems is still considered uncertain (Minderhoud, 1999). The contribution to traffic efficiency of longitudinal driver support systems depends on a variety of factors (e.g. roadway characteristics, actual traffic volume, fleet penetration,

system parameter setting, system reliability, driver and vehicle behaviour). Several studies explore the impacts of these systems on vehicle speed and road capacity by varying some of these factors. For instance, Reiter (1994) reports up to about 10% improved travel time performances feasible, related to different levels of longitudinal support (distance warning: target headway 1.5s, speed control-target: headway 1.5s and deceleration -8m/ss). This latter value is achieved under heavy but free traffic flow conditions. In relation to this, Van Arem et al. (1996) conclude that the introduction of two types of distance keeping (target headway 1.0 sec. and 1.5 sec. with 20% market penetration and target headway 1.0 with 40% market penetration) hardly influences the average speed on motorways (the standard deviation of the average speed however is lower). For a 40% market penetration of vehicle-following systems with target headway 1.5 sec., an average speed reduction was found of about 10%. Consequently, three attribute-levels are defined on the attribute travel time performance: a 'reduction in travel time by 10%'; an 'unchanged travel time', and an 'increase in travel time by 10%'. These levels should make it simple for respondents to make trade-offs between different profiles.

Driving behavioural studies based on real-world observations suggest some positive impact on *fuel consumption* by longitudinal and lateral support (e.g. Bloomfield et al, 1998). However, quantitative estimates have only been given for the case of fully automated driving (AHS). Browand et al (1997) report decreases in fuel consumption for close-following vehicles (platoons) in motorway operation between 5% and 26%, depending on the intervehicle spacing (0.1 to 1.5 vehicle length) and the number of vehicles (2 to 20) within the platoon. On the other hand, some increase in full consumption may also occur due to increased accelerating and decelerating behaviour from a safety point of view. Concluding, some fuel consumption changes may arise from vehicle-following concepts, whereas for the other systems this is uncertain. For the attribute fuel consumption performance, the attribute-levels +5%, 0 and -5% seem to express a plausible range.

In summary, the list of attribute-levels as presented in Table 6-3 results.

Table 6-3: Selected attributes and their levels

distance keeping support	lane keeping support	lane changing support	purchase price	travel time	fuel consumption
warning	none	none	\$500	+10%	+5%
throttle assist.	warning	warning	\$1500	equal	equal
throttle & brake assist.	steering assist.	steering assist.	\$2500	-10%	-5%

6.5.3 The construction of profiles of early AVG systems

In this study, it is assumed that individuals add their part-worth utilities to arrive at their overall utilities. Furthermore, no interaction effects between the attributes are assumed. These assumptions result in a main-effect model: the overall utility is assumed equal to the

sum of the separate part-worth utilities. As argued in subsection 6.4.3, the main-effect model is often used in practice as it minimises the number of profiles to be assessed by individuals, and it has proven to have a reasonable predictive validity. Thus, it is assumed that an attribute-level always contributes in the same amount to the overall utility, regardless of the other attribute-levels included in the profile. Taking a fraction of the full factorial design in the following way, creates a set of profiles for which all main effects can be estimated. Each attribute is assigned to a column of the statistical design: distance keeping is assigned to the first column, lane keeping support is assigned to the second column, etc (see Table 6-4). The numbers 0, 1 and 2 in each column of the statistical design, code the attribute-levels. For instance, for the attribute distance keeping the level distance warning is coded 0, the level throttle assistance is coded 1 and the level throttle and brake assistance is coded 2 (see Table 6-3). The smallest fractional factorial design by which the main effects in our study can be estimated, involves 18 profiles. The profiles to be evaluated by respondents are generated by translating the coded rows of the statistical design into the actual attribute-levels. These profiles are also presented in Table 6-4.

Table 6-4: Main-effects design

no	statistical design	profile					
		distance keeping	lane keeping	lane changing	price (USD)	travel time	fuel consumption
1	0 0 0 0 0 0	warning	none	none	500	+10%	+5%
2	0 1 1 2 1 1	warning	warning	warning	2500	equal	equal
3	0 2 2 1 2 2	warning	steering	steering	1500	-10%	-5%
4	1 0 1 1 1 2	throttle	none	warning	1500	equal	-5%
5	1 1 2 0 2 0	throttle	warning	steering	500	-10%	+5%
6	1 2 0 2 0 1	throttle	steering	none	2500	+10%	equal
7	2 0 2 2 1 0	throttle&brake	none	steering	2500	equal	+5%
8	2 1 0 1 2 1	throttle&brake	warning	none	1500	-10%	equal
9	2 2 1 0 0 2	throttle&brake	steering	warning	500	+10%	-5%
10	0 0 2 1 0 1	warning	none	steering	1500	+10%	equal
11	0 1 0 0 1 2	warning	warning	none	500	equal	-5%
12	0 2 1 2 2 0	warning	steering	warning	2500	-10%	+5%
13	1 0 0 2 2 2	throttle	none	none	2500	-10%	-5%
14	1 1 1 1 0 0	throttle	warning	warning	1500	+10%	+5%
15	1 2 2 0 1 1	throttle	steering	steering	500	equal	equal
16	2 0 1 0 2 1	throttle&brake	none	warning	500	-10%	equal
17	2 1 2 2 0 2	throttle&brake	warning	steering	2500	+10%	-5%
18	2 2 0 1 1 0	throttle&brake	steering	none	1500	equal	+5%

6.5.4 Measuring preferences regarding early AVG profiles

Since in this study the objective is to get more insight into the strength of the preferences of consumer groups regarding alternative systems and not to predict future market shares of early AVG systems, a preference task is preferred to a choice task. As a preference measurement has been chosen, it has to be decided whether to execute a rating or ranking task. A rating task has been chosen in this context, as this type of measurement gives more information on the preference structure of subjects than a ranking task. By definition, ranking only gives information on the preference order for the various alternatives as rating also gives information on the relative preference distance. Furthermore, respondents consider ranking tasks often more difficult to execute, as this requires them to compare all profiles at the same time, and as such many pairwise comparisons have to be made.

The next choice involves the choice of a rating scale on which the respondents have to express their preferences. General considerations in choice involve (Louviere, 1988): (a) a sufficient number of categories to discriminate between the profiles; (b) a numbering or labelling of categories, which does not invite respondents to condense them to a smaller number, and (c) a response dimension that represents the research objective and is clear and easy to use by the respondents. Louviere further argues that the number of categories is dictated by the number of profiles to be evaluated. According to him a 11-point scale should be used when there are 16 profiles or less to be evaluated, for larger designs a 21-point scale should be used.

In this study we are interested in the degree to which different consumer groups consider the 18 profiles as presented in Table 6-4 attractive to have in their vehicle. In addition, as indicated in section 6.4.1, the preferences for profiles regarding driving comfort respectively driving safety are also of interest. For the measurement of these additional preferences, only the technical attributes within the profiles are assumed to be relevant. These technical attributes are likely to influence the driving comfort and safety, whereas cost-benefit attributes are not.

In order to come to appropriate scales for measuring each of these preferences, a test-questionnaire was performed among 30 persons, in which different response scales were tested. Furthermore, the number and transparency of the profiles were tested too.

Regarding the overall attractiveness of the profiles, an 11-point scale from zero (extremely unattractive) to ten (extremely attractive) was favoured by the test-respondents. Most respondents were familiar with this scale as (in the Netherlands) this scale is commonly used in e.g. educational institutions to give marks.

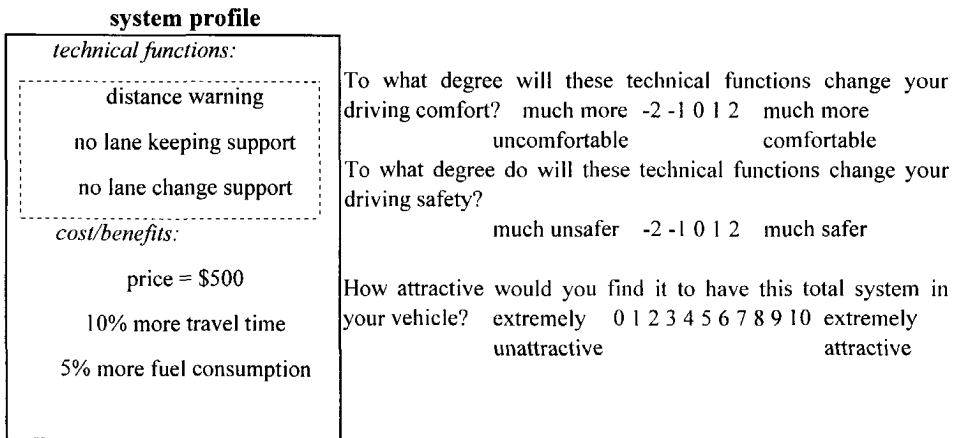
The test-respondents further indicated that they preferred a five-point scale from minus two (much safer/much more uncomfortable) to plus two (much safer/much more comfortable) to scales with more points to express their opinion regarding the comfort and safety of profiles. Furthermore, the test-respondents indicated to prefer a scale with both negative and positive categories as comfort and safety of system profiles are evaluated in terms of changes as compared to today's driving. Finally, using another scale for expressing comfort and safety evaluations, made it more clear to them in considering just

the technical attributes within the profiles and as such these two ratings differed from the overall attractive measurement.

Regarding the number and transparency of profiles, it further appeared that most of the test-respondents understood the profiles rather well but considered the number of 18 profiles far too high to evaluate properly. Based on these remarks, it was decided to distribute two different questionnaires: half of the respondents have received a questionnaire containing the first nine profiles out of Table 6-4 and the other half of the respondents have received a questionnaire containing the last nine profiles. As such, this should minimise the danger that part of the profiles might not be evaluated seriously.

The decision of splitting up the number of profiles among the respondents has a price: individual preference models can not be derived anymore; only models on more aggregate levels can be estimated. This is not really a big problem, given the aim of our analysis. As indicated in the introduction of this chapter, we are interested in exploring the preference structure of potential consumer groups as well as the possible differences between these groups. The specific preference structure of individuals is consequently less important in this context.

Figure 6-2: An example of a profile as presented in the questionnaire and related questions



Summarising, the respondents have been asked in this study to indicate the degree of attractiveness of a system (assuming it would be installed in their vehicle) on a 11-point scale from zero (extremely unattractive) to ten (extremely attractive). Furthermore, the preferences of technical attributes regarding driving comfort and safety were measured on a five-point scale from minus two (much unsafer/much more uncomfortable) to plus two (much safer/much more comfortable) was used. An example of a profile and the related questions as presented in the questionnaire is given in Figure 6-2. The full questionnaire is included in Appendix B.

6.5.5 The estimation of the preference models

As in this study categorical attributes are included, the levels of the attributes have to be coded in order to estimate the preference models. The effect coding of each of the attributes as defined in this study resulted in a so called 'analysis design' as presented in Table 6-5. Since in this study for each attribute three levels have been defined, the effect coding scheme as presented in Table 6-2 can be directly used to transform the main-effects design (Table 6-4) into the analysis design presented (Table 6-5).

Table 6-5: Analysis design

no	statistical design	analysis design																			
		j	1	2	3	4	5	6	x_{j11}	x_{j12}	x_{j21}	x_{j22}	x_{j31}	x_{j32}	x_{j41}	x_{j42}	x_{j51}	x_{j52}	x_{j61}	x_{j62}	
1	000000	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
2	011211	1	0	0	1	0	1	-1	-1	0	1	0	1	0	1	0	1	0	1	0	1
3	022122	1	0	-1	-1	-1	-1	0	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4	101112	0	1	1	0	0	1	0	1	0	1	0	1	-1	-1	1	0	1	-1	-1	0
5	112020	0	1	0	1	-1	-1	1	0	-1	-1	1	0	-1	-1	1	0	1	0	1	0
6	120201	0	1	-1	-1	1	0	-1	-1	1	0	0	1	0	0	1	0	0	1	0	1
7	202210	-1	-1	1	0	-1	-1	-1	-1	0	1	1	0	1	1	0	1	1	0	1	0
8	210121	-1	-1	0	1	1	0	0	1	-1	-1	0	1	-1	-1	0	1	0	1	0	1
9	221002	-1	-1	-1	-1	0	1	1	0	1	0	-1	-1	0	-1	-1	0	-1	-1	0	1
10	002101	1	0	1	0	-1	-1	0	1	1	0	0	1	0	0	1	0	0	1	0	1
11	010012	1	0	0	1	1	0	1	0	0	1	0	0	1	-1	-1	1	-1	-1	0	1
12	021220	1	0	-1	-1	0	1	-1	-1	-1	-1	-1	-1	-1	-1	1	0	1	0	1	0
13	100222	0	1	1	0	1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
14	111100	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
15	122011	0	1	-1	-1	-1	-1	1	0	0	1	0	0	1	0	1	0	1	0	1	0
16	201021	-1	-1	1	0	0	1	1	0	-1	-1	0	1	-1	-1	0	1	0	1	0	1
17	212202	-1	-1	0	1	-1	-1	-1	-1	1	0	-1	-1	1	0	-1	-1	0	-1	-1	0
18	220110	-1	-1	-1	-1	1	0	0	1	0	1	0	1	0	1	1	0	1	1	0	0

no. profile number

x_{j11}, x_{j12} indicator variables for the first respectively second attribute-level of distance keeping

x_{j21}, x_{j22} indicator variables for the first respectively second attribute-level of lane keeping

x_{j31}, x_{j32} indicator variables for the first respectively second attribute-level of lane changing

x_{j41}, x_{j42} indicator variables for the first respectively second attribute-level of price

x_{j51}, x_{j52} indicator variables for the first respectively second attribute-level of travel time

x_{j61}, x_{j62} indicator variables for the first respectively second attribute-level of fuel consumption

In this study, OLS regression techniques are used to estimate the parameters of the preference models, assuming the ratings to be of interval level. The use of OLS techniques has also the advantage that the estimated parameters can be tested statistically (Oppewal & Timmermans, 1992). Once the ratings of profiles by respondents have been collected, their preference model can be estimated straightforward by applying OLS techniques to this

analysis design. In particular, in this study the following main-effect preference model is estimated, using effect coding:

$$V_j = \beta_0 + \sum_k \sum_l \beta_{kl} x_{jkl} + e_j \quad (6.12)$$

where,

V_j = the overall utility or preference of a profile j

β_0 = the regression intercept, indicating the average profile rating

β_{kl} = the regression coefficients, indicating the part-worth utilities of the l -th level of the k -th attribute

x_{jkl} = the effect coded attribute-level l of attribute k of profile j

e_j = an error term

Hence, the estimated regression intercept is equal to the average rating and, by effect coding, the estimated regression coefficients represent the contribution of attribute-levels to the overall utility in terms of deviations from the intercept.

After the model has been estimated, there are different procedures to evaluate the model performance, including (e.g. Timmermans, 1984; Molin, 1999):

- an assessment of the overall goodness of fit of the model;
- to test whether the part-worth utilities are contributing to the overall preferences;
- to examine whether the part-worth utilities are in anticipated directions;
- to examine how well the model predicts the ratings of so-called holdout profiles: profiles which have been rated by respondents but have not been used to estimate the model;
- to research whether different groups have significantly different preferences.

The overall goodness of fit of a preference model estimated by OLS regression techniques, is expressed by the coefficient of determination, also known as the R-square (Chatfield, 1983). The R-square measures how well the estimated model fits the data. It enables one to compare the relative explanatory power of independent variables (i.e. the coded attribute-levels), explaining the dependent variable (the profile ratings). The R-square is the ratio of the regression sum of squares to the total sum of squares. It has a value between zero and one: the higher the values of R-square, the better the model fits the observed data and consequently the better the model predicts a dependent variable.

In order to test whether the estimated part-worth utilities contribute significantly to the overall preferences, a t-test is used. This procedure enables one to test whether each of the estimated parameters in the preference model significantly differ from zero.

The examination whether the part-worth utilities are in anticipated directions is difficult regarding the technical attributes defined in this study. As shown in section 6.2, previous research does not point out a unidirectional relationship between overall preferences and operational system characteristics. Only, as for the cost-benefit attributes, it is reasonable to

be expected that the part-worths will show decreasing tendencies as respectively the levels of price, travel time and fuel performance increase.

The examination of how well the preference model predicts the ratings of a set of holdout profiles involves a comparison of the scores, given for these profiles, by the respondents and also the predicted scores by the estimated preference model. In this study two holdout profiles have been included in the questionnaire in order to perform this examination.

Finally, in this study we are also interested whether different groups have significantly different preferences. In particular the differences in preferences between different driver groups (car, bus and truck) as well as the differences in preferences between different fleet-operator groups (car, bus and truck) are of interest. This can be analysed by testing whether the regression differentials between groups significantly differ from zero. In general, the procedure conducted to identify differences between groups is as follows. Suppose we want to examine whether group A of respondents differ significantly in their preferences as compared to group B of respondents. Now for respondents of group A, the analysis design is replicated and the columns with the coded attribute-levels of the replication are multiplied by +1 and for the respondents of group B the analysis design is replicated and the columns with the coded attribute-levels of the replication are multiplied by -1. Consequently, in addition to the original set of parameters a new set of parameters is estimated, the so-called contrast parameters. The analysis involves researching whether the contrast parameters contribute to the explained variance. For those contrast parameters that significantly differ from zero (t-test), the part-worth utilities significantly differ (and hence the preference model) between group A and B.

6.5.6 The simulation of preferences

After the specification of the models, it is now possible to simulate the safety, comfort and attractiveness for all possible combinations of attribute-levels presented in Table 6-3. The preference for each profile of interest can be calculated by adding the related part-worth utilities. Furthermore, for the continuous attributes price, travel time and fuel consumption, the part-worth utilities of intermediate attribute-levels can be derived by interpolation. This allows the simulation of preferences for all profiles, which can be constructed within the range of these continuous attribute-levels.

6.6 survey design

After the design of the conjoint experiment, there are some issues which have to be clarified before the conjoint experiment can be conducted in field research.

A first issue involves the experience that respondents might need some exercise in performing a preference task. Respondents often consider the evaluation of the first profiles within a list of profiles more difficult as compared to latter profiles when some experience is gained with the interpretation of profiles and the procedure for evaluation. This means

that the ratings of the first profiles in the questionnaire might be less of less use as compared to the evaluations respondents make when proceeding through the list of profiles, which might induce some bias in the preference model. In order to avoid that always the same profiles are victim of this 'learning' effect, one has to vary the orders of profiles over respondents within the conjoint task. Therefore, in this study, three different orders of the profiles to be evaluated were used within the questionnaire. We already mentioned that half of the respondents received a questionnaire containing the first nine profiles out of Table 6-4 and the other half of the respondents received a questionnaire containing the last nine profiles. By including three different orders of profiles, 6 different variants of questionnaires had to be distributed. Furthermore, each questionnaire started and ended with a holdout profile. The fact that each questionnaire started with the same (holdout) profile implies that the first holdout might be of less use for analysing how well the model predicts the ratings of this profile.

The questionnaire consisted of two parts. In the first part of the questionnaire, the respondents had to evaluate eleven different profiles. In the second part, the respondents were questioned on several background characteristics. All respondents were invited to indicate their basic social characteristics (gender, age and level of education). The vehicle driver respondents were further questioned about the number of years they had owned their license, their type of vehicle ownership, the price of their vehicle, and their vehicle use. Fleet-operator respondents were questioned on their fleet size, the prices of vehicles within their fleet and the amount of kilometres driven by their fleet. Finally, the familiarity of the respondents with the systems questioned was measured.

This information enables the construction of some profile of the responding group and can be used to analyse representativeness. Furthermore, possible differences in characteristics of respondents might explain possible differences in their preference behaviour. The choice of asking these particular characteristics of respondents was based on the results of studies performed previously. These studies showed that these characteristics are likely to influence the preferences for transport telematics in general (e.g. Nijkamp et al, 1996).

A last issue involves the determination of the sample size. In general, conjoint analysis can be applied to individuals, market segments or entire markets. At the individual level, for example, conjoint analysis can be used to explore the preferences of a buyer about new AVG systems. In this case a sample size of one would be sufficient. Similarly, conjoint studies of limited markets, such as the major vehicle industries, can be based on just 10 to 15 respondents. For market segments, conjoint results tend to stabilise after about 30 to 60 respondents. Literature suggests that it has to be tried to have at least 30 to 60 respondents per market segment under study (Orme, 1998). These figures account for conjoint experiments in which the respondent evaluates all profiles enabling the estimation of models at individual level. As indicated earlier in this study, each respondent evaluates only half of the profiles. Hence, the rules of thumb should be doubled, implying 60 to 120 respondents for each consumer group of interest. In this study these groups are drivers and fleet-operators of cars, buses and trucks. Regarding the car-driving consumers we are

further interested whether business drivers and private drivers differ in their preferences. The Delphi study pointed out that business drivers are expected in particular as a first group of early AVG systems. Hence, business drivers and private drivers will be considered different consumer groups in this study, implying that 60 to 120 respondents are needed for each group. In addition, regarding the group of truck fleet-operators some differentiation was used as this group is highly heterogeneous in terms of varying fleet sizes. In the Netherlands the large majority of truck fleet-operators has a small fleet as relatively few fleet-operators have large fleets. Furthermore, as truck fleet-operators with large fleets involve a substantial part of the total truck fleet it is important to get insight into their preferences. In order to include fleet-operators with large truck-fleets, this group was oversampled also.

The number of questionnaires to be distributed depends on the expectations regarding the response. Unfortunately, no figures on responses from other conjoint studies have been found. In practice, it appears that conjoint measurements are often conducted by personal interviews or by internet and as such the response is not reported. Hence, we are forced to rely on experiences gained with the response regarding common questionnaires conducted by paper and mail. These experiences point out that a response of about 20 percent is rather normal. As such, we have to oversample by a factor five.

6.7 Conclusion

The aim of this chapter involved the specification of an approach to collect in-depth knowledge about consumer behaviour regarding early AVG systems. An overview of studies performed in this field points out that empirical results for consumer preferences regarding AVG systems show different results. Furthermore, it appears that several approaches have been used to assess user preferences regarding AVG and that the reasons to choose between different possible approaches are often based on practical considerations. In particular, it appears that most studies lack some theoretical background on preference behaviour. Therefore, in this chapter a general conceptual view on preference and choice behaviour has been specified and operationalised in order to model the preferences of consumers regarding early AVG systems. According to this view, individuals are assumed to evaluate alternative products or services as bundles of attributes and the preference for and/or choice of a particular alternative are based on combining part-worth utilities of separate attributes.

The approach of conjoint analysis has been argued most appropriately to determine the part-worth utilities of individuals regarding AVG systems, in order to be able to predict preferences of individuals regarding the different AVG systems under consideration. By using this approach, the influence and the relative importance of several system attributes on overall preferences can be studied in a realistic way. In particular, by this approach, individuals have to evaluate complete AVG systems and as such the measurement task bears close resemblance with the behaviour in real markets and the trade-off between the attributes is taken into account. Hence, the estimated preferences potentially have higher

validity as compared to measurement approaches in which respondents are asked to evaluate attributes separately.

Furthermore, conjoint analysis enables the analysis of the possible differences in preferences of various consumer groups as well as the influence of background characteristics of respondents regarding their overall preferences. Finally, a well-developed set of measures is available to analyse the performance of the preference models estimated.

In the next chapter the preference models of consumers regarding early AVG systems will be estimated and discussed, based on a large survey conducted among different consumer groups.



Chapter 7.

Consumers' preferences regarding early AVG implementation

7.1 Introduction

This chapter explores the preferences of potential consumers regarding AVG systems supporting drivers in proper distance keeping, lane keeping and lane changing². The overall attractiveness, driving comfort and driving safety have been measured using the conjoint analysis approach as presented in the previous chapter. Drivers as well as fleet-operators of cars, trucks and buses have been questioned about their preferences regarding several alternative AVG systems. Furthermore, some background characteristics of respondents have been collected which could be relevant to preference behaviour.

The structure of this chapter is as follows. Firstly, the response and relevant characteristics of the respondents are presented in section 7.2. Next, in section 7.3, the overall attractiveness, driving comfort and driving safety of various systems is analysed based on estimated preference models for the total sample. In section 7.4 the possible differences in preferences among drivers of cars, buses and trucks respectively fleet-operators of cars, buses and trucks are examined. In section 7.5 the influence of background characteristics of drivers respectively fleet-operators as to their preferences, is analysed. Finally, conclusions are drawn in section 7.6.

² Part of the results of this study have been presented in Marchau et al (1999)

7.2 Response and profile respondents

In this section the response and profile of respondents is presented. In subsection 7.2.1 the response and social characteristics of the response group are discussed. Subsection 7.2.2 summarises the vehicle- and trip characteristics of the driver respondents respectively the fleet- and transport characteristics of the fleet-operator respondents. Finally, in subsection 7.2.3, the familiarity of the respondents with the systems questioned is discussed.

7.2.1 Response rate and characteristics

During October and November 1998, 3350 questionnaires were distributed among drivers and fleet-operators of cars, buses and trucks. Drivers were approached randomly at different gas stations along Dutch motorways during different days, as the AVG systems questioned in the questionnaire were presented to be for motorway-use only. Truck and bus drivers were approached by mail, as most of these drivers take fuel at their company location. Fleet-operators were selected from the register of the Dutch Chamber of Commerce and databases of branch-organisations, and were also approached by mail. After three weeks reminders were sent to the fleet-operators in order to improve the response. A total of 490 questionnaires was returned within a period of 6 weeks, of which 485 appeared to be of use. The response degree of different groups is presented in Table 7-1.

The response rates varied among the distinguished consumer groups between 9.3% and 22.2%. The lowest responding groups were fleet-operators. Although the response of fleet-operators seems low, there are relatively few fleet-operators with large fleets in the Netherlands both for cars, buses and for trucks. Therefore, a low response in this context could still involve a substantial part of the total vehicle fleet. Whether this is the case for this sample of fleet-operators will be discussed in subsection 7.2.2. The average degree of response was 14.5 %. This rate seems reasonable, given the high complexity of the questionnaire (see Appendix B) in combination with the fact that about 80% of the respondents indicated they were hardly or even not familiar at all with innovative AVG systems.

Table 7-1: Response and sample structure related to different groups

groups	questionnaires distributed	absolute response	relative response	group share sample
car drivers	900	200	22.2%	41.2%
bus drivers	450	61	14.0%	12.6%
truck drivers	450	59	13.1%	12.2%
(subtotal drivers)	1800	320	17.8%	66.0%
car fleet-operator	400	37	9.3%	7.6%
bus fleet-operator	250	32	12.8%	6.6%
truck fleet-operator	900	96	10.6%	19.8%
(subtotal fleet-operator)	1550	165	10.6%	34.0%
total	3350	485	14.5%	100.0%

The basic social characteristics of the total sample as well as of the different groups are summarised in Table 7-2. Characteristics of specific groups are marked only in italics in the table if they differ significantly between the groups they have been compared to. Considering the total group, most respondents were male (90%) and the mean age of participants was about 40 years. The respondents were rather well educated: 42.6% of the respondents indicated they had a bachelor's degree or a higher degree; 19.2% of the respondents finished secondary school, and 38.2% had a lower or intermediate vocational education.

Considering different groups, some differences on gender and education were found to be statistically significant. The number of females was significantly higher for the drivers as compared to the fleet-operators. In particular, there were more female car drivers represented among the car drivers as compared to the other groups. No significant differences were found concerning the mean age between the groups. On average, drivers were significantly better educated than fleet-operators, although this only yields for the car driver group. In particular the car drivers were well educated, but the bus and truck drivers were less educated. The education of fleet-operators followed a similar pattern. Car fleet operating respondents were on average substantially higher educated than truck and bus operators.

Table 7-2: Social characteristics of respondents

	total sample	drivers	fleet-operators	driver groups			fleet-operator groups		
				car	bus	truck	car	bus	truck
gender:									
male	90.2%	86.5% ¹	97.5%	80.3% ²	93.4%	100%	97.3%	100%	96.8%
female	9.8%	13.5%	2.5%	19.7%	6.6%	-	2.7%	-	3.2%
n	480	318	162	196	61	59	37	31	94
mean age:	40.1	40	40.1	39.6	42.4	38.9	37.8	41.6	40.5
(std)	(10)	(10)	(10)	(10.3)	(9.9)	(9.1)	(9.5)	(10.9)	(9.9)
n	478	315	163	197	61	58	37	32	94
education:									
less than sec. school	38.2%	34.2% ³	46.2%	14.9% ⁴	60%	71.2%	31.4%	53.1%	49.4%
sec. school	19.2%	17.9%	21.8%	10.3%	36.7%	23.7%	20%	15.6%	24.7%
bachelor or higher	42.6%	47.9%	32.1%	74.7%	3.3%	5.1%	48.6%	31.3%	25.8%
n	478	317	161	198	61	59	37	32	92

Pearson Chi-square values have been computed to test whether the differences on social characteristics between different groups were statistically significant at 0.05 level. The following values have been found significant: ¹Chi-square = 14.8; ²Chi-square = 39.2; ³Chi-square = 23.5; ⁴Chi-square = 252.2.

Only the representativeness on social characteristics of the car-driving respondents has been analysed statistically, due to limited available statistics for the other groups at national level. The results are presented in Table 7-3. The chi-squares have been computed to test the representativeness of the sample. They were found to be too large to assume representativeness at a 0.05 level. Consequently, if the social characteristics of the car driver respondents appear to be of influence on their preference structure, the results of the overall analysis for car drivers cannot be generalised as being applicable to the national car-driving population. If no such relationships appear, the limited representativeness has no affect on the conclusions.

Table 7-3: Representativeness of car-driving respondents

characteristic	gender		age					education		
	male	female	18-24	25-39	40-49	50-64	65+	less than sec. school	sec. school	bachelor or higher
sample	161	39	6	95	58	34	3	29	20	145
national level	129	71	16	71	43	43	23	105	50	39
Chi-square	22.4		37.5					361.1		
n	200		196					194		

7.2.2 Driving and fleet characteristics of respondents

The characteristics of the driver respondents regarding their license ownership, vehicle ownership, vehicle price and vehicle use are summarised in Table 7-4. On average the driver respondents of cars, trucks and buses indicated to have had their driving license for about 20 years.

The ratio of private and commercial car owners of the car-driving respondents appeared to be about fifty/fifty. This is very much out of balance with Dutch national data on car ownership: 84% of the cars in the Netherlands is privately owned (Korver & Vanderschuren, 1995). The high number of business drivers that participated in the survey is probably related to the fact that the questionnaire was distributed among car drivers at motorway gas stations. These places are likely to be more frequently visited by business drivers as compared to private car drivers. At motorway gas stations the prices of gas are higher as compared to gas stations at lower road levels and business drivers can usually claim these expenses. Furthermore, the fact that almost half of the car-driving respondents indicated to be business drivers, likely influenced the (on average) high vehicle prices as well as the amount of kilometres travelled on motorways as compared to national statistics. While cheap and middle class cars were less represented, relatively many drivers with expensive cars participated in the survey.

The average new prices of vehicles indicated by bus and truck-driving respondents were logically much higher than of cars. The variation of retail prices of vehicles was the largest for the bus-driving respondents. Drivers with low-priced buses as well as drivers with very expensive buses participated in the survey. In general about 25% of the bus-driving

respondents indicated a price lower than Dfl 250,000, 55% between Dfl 250,000 and Dfl 500,000 and 20% of the bus drivers indicated a price above Dfl 500,000.

The average amount of kilometres weekly driven by the car driver respondents was 664 km, which is more as two times as much as compared to the average amount of car kilometres weekly driven at national level: 313 km (CBS, 1998b). Next, the amount of kilometres driven by car varied considerably: 17% of the car-driving respondents drove less than 250 km on motorways per week, about 50% between 250 and 500 km and about 25% more than 750 km.

Bus-driving respondents drove weekly an average of 1564 kilometres on motorways; for truck drivers this was 2754 km. Also for these types of vehicles this is substantially more as compared to national figures: in 1996 on average, a bus drove about 1300 km per week and a truck drove about 1900 km, depending on the type of truck (CBS, 1998a). Again among bus drivers the deviation is large as compared to truck drivers: some bus drivers drove on average a few hundred kilometres, others drove more than five thousand a week on motorways.

Table 7-4: Vehicle and trip characteristics of the driver groups

characteristic	all drivers	driver groups		
		car	bus	truck
ownership:				
private	-	54%	-	-
business	-	46%	-	-
n	-	200	-	-
years driving license:				
mean (std) ¹	20.4 (10)	19.4 (10.0)	23.6 (10.3)	20.4 (9.2)
n	320	200	61	59
price new vehicle in Dfl:				
mean	140585	46560	382291	244256
(std)	(181865)	(22419)	(253266)	(121172)
n	291	191	55	45
weekly driven km on motorw.:				
mean	1223	664	1564	2754
(std)	(1130)	(466)	(1416)	(783)
n	319	199	61	59

¹ std = standard deviation

The characteristics of the fleet-operating respondents regarding their fleet size, vehicle price and vehicle use are summarised in Table 7-5. The sizes of fleets varied considerably within each group. Fleet-operators of small car-fleets participated in the survey as well as fleet-operators of very large fleets (up to 15,000 vehicles). With respect to truck operators the fleet sizes varied less: 40% of the participating truck fleet-operators had a fleet of less than 10 vehicles, another 40% of the fleet-operators indicated to have a fleet of 10 to 50 vehicles and the remaining 20% of the truck operators controlled fleets of more than 50 vehicles. Also the fleet sizes of the bus operating respondents varied considerably. This was

caused by two respondents indicating to be responsible for very large fleets of 100 respectively 500 vehicles, whereas the remaining respondents operated a maximum of 57 vehicles. In the Netherlands there are relatively few companies with large fleets as compared to the amount of companies with small fleets (CBS, 1997; CBS, 1998a). Therefore, the low response rates among fleet-operators in this survey still implies coping with a substantial part of the total vehicle fleet.

The average price levels of a new vehicle within a fleet were about the same as the levels indicated by the drivers. Fleet-operators of cars and buses, however, indicated that the vehicles within their fleet drove, on average, significantly more than was indicated by the drivers of cars and buses. For truck-operators this number was lower. As fleet-operators indicated the amount of kilometres driven on all roads, not on motorways only, fleet-operators were also asked about the geographical area(s) in which the vehicles mostly operate.

Considering all fleets together, the vehicles were mostly used at national and international scale, indicating frequent use of motorways. Car fleet-operators indicated that their vehicles operated most of the times at national level; participating fleet-operators of trucks operated mostly at international roads. A nearly uniform distribution over the different geographical areas has been found for buses.

Table 7-5: Fleet characteristics of the fleet-operators

characteristics	all fleets	specific fleets		
		car	bus	truck
fleet size:				
mean	630	2674	40	33
(std) ¹	(2262)	(4198)	(87)	(42)
n	164	37	32	95
price new vehicle in Dfl:				
mean	223287	46581	398906	232953
(std)	(148095)	(28575)	(119931)	(100453)
n	164	37	32	95
weekly km driven:				
mean	1903	795	1721	2384
(std)	(925)	(485)	(722)	(708)
n	163	36	32	95
operating transport area ²				
regional	35.8%	40.5%	71.9%	21.9%
national	61.8%	78.4%	65.6%	54.2%
international	64.2%	13.5%	68.8%	82.3%
n	165	37	32	96

¹ std = standard deviation; ² respondents could indicate more than one option

Summarising, the characteristics as described above show that each responding group appeared to be rather heterogeneous in terms of vehicle prices and use respectively fleet prices and use. Furthermore, as the survey is focusing on 'motorway users' only, the

profiles of responding groups differ from the national figures. This means that the preferences of the sample cannot be automatically generalised to the total population of relevance. This depends on whether the characteristics of respondents are of influence on their overt preference behaviour. Whether this is the case, will be analysed in section 7.5. However, it is clear that each consumer group of interest in this study is represented by a reasonable number of respondents. Hence, as each group is represented by a sufficient number of cases, it is justified to consider the measured preferences as a first insight into how these groups feel about AVG systems.

7.2.3 The familiarity of respondents with AVG systems

Finally, all respondents were asked whether they were familiar with the AVG systems questioned in the questionnaire. The results are presented in Table 7-6. About 80% of the respondents indicated that they were hardly or not at all familiar with the systems questioned whereas 20% was quite familiar with the systems. Overall, the different drivers groups did show similar familiarity patterns as on average: 20-30% indicated no to be familiar, some 50% of the drivers was limited familiar and 20% was quite familiar.

With respect to fleet-operators this was not the case. Car fleet-operators were most familiar with the systems questioned, followed by bus fleet-operators. Truck operators participating in the survey were rather unfamiliar with the systems questioned. Only 7.6 % of these respondents indicated to be quite familiar.

Table 7-6: Familiarity of respondents with AVG systems

Groups	not familiar	moderately familiar	quite familiar
total sample (n=478)	23.8% ¹	55.9%	20.3%
car driver (n=199)	29.1%	50.8%	20.1%
bus drivers (n=59)	20.3%	57.6%	22.0%
truck drivers (n=59)	27.1%	50.8%	22.0%
car fleet-operators (n=37)	8.1%	48.6%	43.2%
bus fleet-operators (n=32)	6.3%	68.8%	25.0%
truck fleet-operators (n=92)	25.0%	67.4%	7.6%

¹23.8% of the group indicated to be not familiar with the systems questioned

7.3 Preferences of all respondents

In this section aggregate preference models for the total group of respondents are estimated and discussed. First, a model regarding the overall attractiveness of systems is estimated in subsection 7.3.1. Next, in subsection 7.3.2, the comfort and safety models are estimated. Finally, the performance of the models is discussed in 7.3.3.

7.3.1 The 'attractiveness' preference model

The evaluation by all respondents regarding the attractiveness of the profiles resulted in the preference model as presented in Table 7-7. The estimated part-worth utilities can be interpreted as deviations from the average profile rating (intercept) on an 11-point scale from zero to ten, with zero expressing extreme unattractiveness and ten expressing extreme attractiveness. Note that due to the effect-coding of attribute-levels only $n-1$ parameters are estimated for each of the n attribute-levels. These parameters can be interpreted as the part-worth utilities of the first and the second attribute-level (see subsection 6.4.5).

The second column gives the t -values, which are used to test whether the estimated part-worth utilities contribute significantly to the overall preferences. As only $n-1$ parameters are estimated for each of the n attribute-levels, only for these attribute-levels t -values are calculated. Except for the price of \$1000, all attribute-levels influence the overall profile attractiveness significantly at a 0.05 level.

The third column indicates the relative importance of the attribute in relation to the overall utility. The relative importance of an attribute is deduced from the absolute difference between the highest and lowest part-worth utility of the attribute-levels of an attribute. This range can be interpreted as the contribution to the sum of the ranges across all attributes. By dividing the range of an attribute by the sum of ranges of all attributes considered in the model, the relative importance of an attribute is represented in percentages, which makes a comparison across attributes possible. This measure is often used in conjoint analysis to indicate the importance of an attribute as compared to other attributes (Hair et al, 1998).

An indicator for the performance of the model is given by the R-squares which express the extent to which the estimated model fits the observed data. The R-square at individual level is low, indicating that individual ratings vary considerably. The R-squares will be further discussed in subsection 7.3.3.

The intercept of the estimated model is 4.89. This implies that, on average, the respondents consider to be the profiles somewhat unattractive. Whether this corresponds to with the findings in other studies performed in this field is difficult to say, as these empirical studies on consumer preferences regarding AVG systems have shown different results and different types of measurements.

Looking more closely at the individual attributes, the derived part-worth utilities for the attribute *distance keeping* are for distance warning 0.3, for throttle assistance -0.12 and for throttle and brake assistance -0.18 . This means that a distance warning system is preferred to throttle assistance or to throttle and brake assistance, assuming all other things to remain equal. Furthermore, this implies that systems with throttle assistance on distance keeping are preferred to systems with throttle and brake assistance. However, the preference difference between these two is rather small, indicating that people, on average, are rather indifferent to the way the system intervenes regarding distance keeping.

Table 7-7: Attractiveness preference model of all respondents

attribute	part-worth utility	t-value ¹	attribute importance
<i>distance keeping</i>			12.03
warning	0.30	5.507	
throttle assistance	-0.12	-2.242	
throttle & brake assistance	-0.18		
<i>lane keeping</i>			11.78
none	-0.16	-2.981	
warning	0.31	5.779	
steering assistance	-0.15		
<i>lane changing</i>			17.54
none	-0.20	-3.676	
warning	0.45	8.240	
steering assistance	-0.25		
<i>price</i>			20.80
\$500	0.39	7.147	
\$1000	0.05	0.919	
\$1500	-0.44		
<i>travel time</i>			20.05
+10%	-0.47	-8.751	
equal	0.14	2.541	
-10%	0.33		
<i>fuel consumption</i>			17.79
+5%	-0.42	-7.793	
equal	0.13	2.389	
-5%	0.29		
regression intercept	4.89	128.078	
R ² group level	0.982		
R ² individual level	0.079		
n	485		

¹As only $n-1$ parameters are estimated for each of the n attribute-levels, only $n-1$ t -values are given for each attribute.

As for the attributes *lane keeping* and *lane changing* support, we see that a warning device is preferred to no support or steering assistance. So, it is to be concluded that there is an optimum for both lane keeping and lane changing systems: the overall utility increases between no support and warning, and decreases between warning and steering assistance. This indicates that warning systems are significantly favoured to no support or controlling systems in this context. Hence, there appears to be a need for driving support on lane keeping and lane changing. Finally, for both lane keeping and lane changing, the difference between the part-worths for no support and steering assistance are small. This indicates that the respondents are, on average, indifferent whether the system does not support or supports by steering assistance.

The part-worth utilities of the attributes *price*, *travel time* and *fuel consumption* each show, as expected, decreasing tendencies: increases in price, travel time or fuel consumption decrease the overall utility contribution (see Figure 7-1). As for the attribute price, the estimated part-worth utilities even indicate a nearly perfect linear relationship, given the fact that the part-worth of \$1000 is not significant. This is not the case for both other attributes. Regarding the attribute travel time, the part-worth utility increases two and a half time faster between the levels 10% more travel time and equal travel time as compared to the part-worth utility of the levels equal travel time and 10% less travel time. As for fuel consumption the part-worth utility increases three and a half time faster between the levels +5% and equal in comparison with the part-worth utility of the levels equal and -5%. An equal travel time and fuel consumption give positive part-worth utilities. These tendencies indicate that systems which negatively influence travel time and fuel consumption, are strongly disfavoured in comparison with systems which do not. Furthermore, this implies that the overall utility only limited increases by systems which influence travel time and fuel consumption positively.

The estimated model further points out that *price* is the most important attribute, closely followed by respectively *travel time*, *fuel consumption* and *lane changing*. The least important are the attributes *distance keeping* and *lane keeping* respectively, which are almost equally important. However, one has to be careful with this measure of attribute importance, because this could be related to the range of attribute-levels chosen. If, for instance, a smaller range of attribute-levels would have been chosen, e.g. \$750, \$1000 and \$1250, the range of the part-worth utilities would likely become smaller too. This, in turn, would give a smaller absolute difference between the highest and the lowest part-worth utility, i.e. a lower attribute importance of the attribute. Hence another attribute might become more important. Consequently, conclusions on attribute importance can only be drawn within the range of attribute-levels specified in this study and cannot be generalised automatically.

As mentioned in the previous chapter (subsection 6.5.6), now the overall preferences for all possible profiles, constructed from the pre-specified attribute-levels of the cost-benefit attributes, can be calculated. These preferences result from the summing up the accompanying part-worth utilities. For instance, consider the technically most advanced alternative, at the lowest price-level with the best operating performance. This is a system with throttle and brake assistance, lane steer assistance, lane change steer assistance, at a price of \$500, which improves travel time with 10% and reduces fuel consumption by 5%. The overall utility for this profile is $4.89 + (-0.18) + (-0.15) + (-0.25) + 0.39 + 0.33 + 0.29 = 5.32$. Hence, this system is rated as moderately attractive.

Given the model the most preferred profile by all respondents is simply determined by selecting for each attribute the attribute-levels with the highest part-worth utility. Consequently, the system with the highest overall utility supports distance keeping, lane keeping and lane changing by warnings, at a price level of \$500, improving travel time and fuel consumption with respectively 10% and 5%. This system has an overall utility of 6.97.

Similarly, the least preferred system by the sample is determined by considering the lowest part-worths. This results in a system which supports distance keeping by throttle and brake assistance, which does not have lane keeping support, which provides lane change support by steering, at a price of \$1500, and which increases travel time and fuel consumption with respectively 10% and 5%.

Furthermore, we are able to simulate preference behaviour for new profiles with

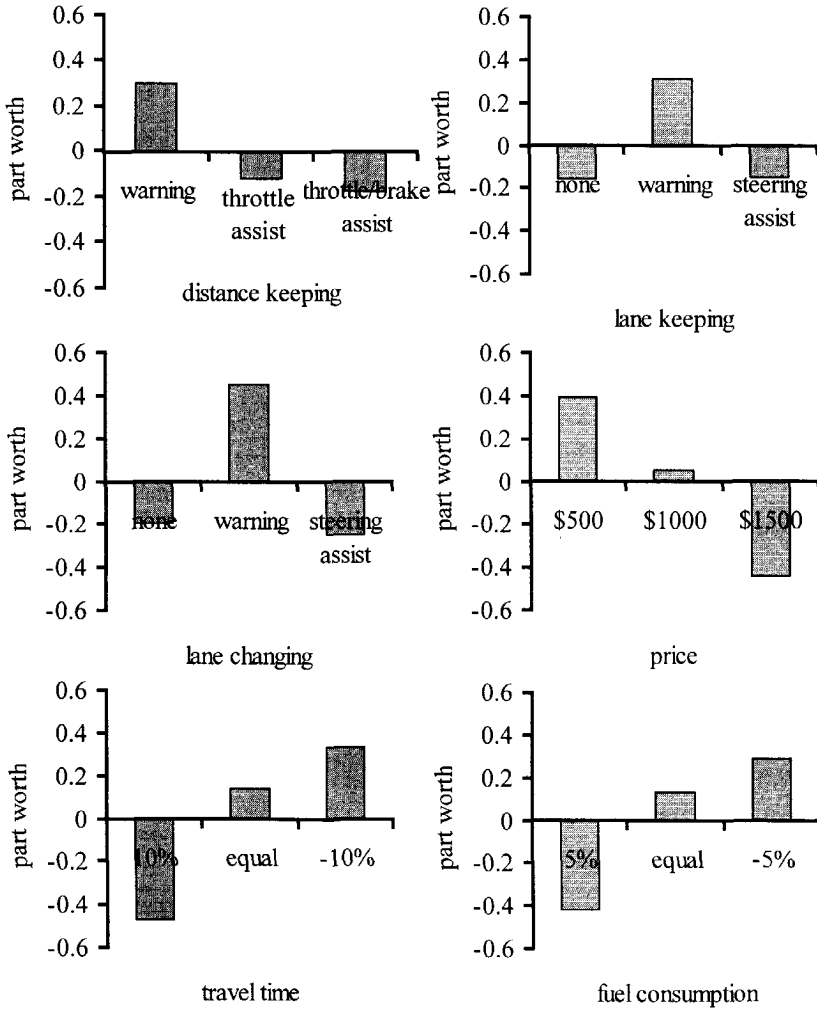


Figure 7-1: The part-worth utilities regarding the attractiveness of AVG

intermediate attribute-levels (continuous attributes only). The related part-worth utilities are derived by interpolation, assuming linearity between the extreme values. A price-level of \$750, for instance, gives a part-worth of 0.17; a travel time improvement of 5% gives a part-worth utility of 0.24; and a decrease of fuel consumption of 2.5% gives a part-worth utility of 0.21.

7.3.2 The 'comfort' and 'safety' models

Next to attractiveness, the respondents indicated to what degree they expected that the technical attributes of the profiles would influence their driving comfort and safety. The respondents could express their opinion on a five-point scale from minus two to plus two. Minus two indicates very uncomfortable and unsafe, whereas plus two expresses very comfortable and very safe respectively. The respondents' evaluation resulted in the comfort- respectively safety model presented in Table 7-8.

As for the attractiveness model, the estimated part-worth utilities can be interpreted as deviations from the average profile rating (intercept). The *t*-values show that all estimated part-worth utilities contribute significantly at a 0.05 level to the overall comfort-respectively safety evaluation. The relative importance of the attributes to the overall utility is computed in a similar way as for the attractiveness model. The R-squares for the comfort- and safety model show a similar pattern as for the overall attractiveness, indicating that individual ratings vary considerably.

On average, the respondents evaluated the systems to be moderately comfortable (intercept is 0.47) and moderately safe (intercept is 0.57) as compared to driving without these systems. The derived part-worth utilities further indicate similar trends for comfort and safety: for each attribute the part-worths for warning levels are positive whereas for assisting levels these are negative. This implies that warning devices are evaluated to be more comfortable and more safe than assisting devices.

For *distance keeping* the part-worth utilities decrease rapidly between the levels warning and throttle assistance and little (regarding comfort) or not (regarding safety) between the levels throttle assistance and throttle and brake assistance. Hence, the implementation of driver support systems which actively support the driver on distance keeping is expected to decrease the overall perceived driving comfort and driving safety.

For the attributes *lane keeping* and *lane changing*, again an optimum appears: the part-worth utilities increase between no support and warning and decrease between warning and steering assistance. The general tendency, found in this study, namely that warning systems are evaluated to be more comfortable and more safe than systems which take temporary control, might be attributed to the fact that respondents consider the latter category of systems not sufficiently capable to take over the vehicle driving task in a proper way and/or systems might take the wrong actions (and hence would make vehicle driving unsafe). As such, the driver would have to pay attention whether a system initiates and executes driving actions properly, in addition to the basic driving task. This extra task in turn might influence comfort and safety negatively.

Considering the differences between the lowest and the highest part-worth utilities of an attribute again, the importance of the different attributes for comfort and safety can be computed. Both for comfort and for safety, lane changing appears to be the most important system attribute, followed by lane keeping and distance keeping respectively. The differences between the relative importances of lane keeping and distance keeping is much larger for both comfort and safety as compared to the attractiveness model.

Finally, the estimated part-worth utilities for the comfort- and safety model indicate that the respondents evaluate the same systems as most comfortable and most safe respectively most uncomfortable and most unsafe, as in case of the overall attractiveness.

Table 7-8: The comfort model and the safety model

attribute	comfort			safety		
	part-worths comfort	t-value ¹	attribute importance	part-worths safety	t-value ¹	attribute importance
<i>distance keeping</i>			26.09			26.47
warning	0.15	6.277		0.18	7.372	
throttle assistance	-0.06	-2.347		-0.09	-3.816	
throttle & brake	-0.09			-0.09		
<i>lane keeping</i>			34.78			34.31
none	-0.06	-2.517		-0.07	-3.029	
warning	0.19	7.617		0.21	8.809	
steering assistance	-0.13			-0.14		
<i>lane changing</i>			39.13			39.22
none	-0.06	-2.506		-0.10	-4.298	
warning	0.21	8.546		0.25	10.570	
steering assistance	-0.15			-0.15		
regression intercept	0.47	27.124		0.57	33.436	
R ² (group level)	0.91			0.86		
R ² (individual level)	0.04			0.06		
n	485			485		

¹As only n-1 parameters are estimated for each of the n attribute-levels, only n-1 t-values are given for each attribute.

7.3.3 Performance of models

The measures of performance which remain to be discussed are related to the predictive power of the estimated models. As explained in subsection 6.4.5 the coefficient of determination, R-square, is one of such measures and represents the explanatory power of the regression model. It measures how well the model can predict the observed data used to estimate the model. At the aggregate level the predictive power of all models has been found to be high. This is not surprising as in these cases the R-square is based on a model

estimation of average profile ratings of all individual ratings. Thus, individual differences are already sorted out before model estimation. At individual levels the R-squares have been found to be low for each model, which indicates that the predictive power of the models for individual preferences are low. Aggregate models in general yield poor results in terms of predicting individual preferences. In case of more homogeneous preference behaviour with respect to the evaluation of profiles, the R-square would increase.

The most severe test regarding the predictive validity of the estimated models is performed by testing the ability to correctly predict the consumers' behaviour on real markets (Molin et al, 1999). As in general the AVG systems questioned in the survey are not available on the market, it is impossible to perform this test. Therefore, one usually tests the model's ability to predict the observations for new alternatives, i.e. the ratings observed for holdout profiles.

The degree to which the estimated models are able to predict the individual scores of holdout profiles is presented in Table 7-9. In the first column the predictions for two holdout profiles based on the estimated models for overall attractiveness, comfort and safety are given. The second column gives the average ratings as observed in reality. An indication of the prediction accuracy is given by the absolute difference between the predicted rating and the observed rating for the holdout profile. The third and fourth column present the mean of absolute differences, averaged across the individuals, between predicted and observed behaviour and the standard deviation of absolute differences respectively.

Table 7-9 shows that the prediction errors, represented by the mean absolute difference, differ considerably among the different holdouts. In particular the errors made for predicting holdout 2 appear to be large. The error for attractiveness is 2.6 on an eleven-point scale and for comfort and safety this error is about 1.2 on a five-point scale. These errors indicate a bad performance of each of the models in this context. This might be explained by the fact that each questionnaire started with holdout 2 and ended with holdout 1. As discussed in section 6.6, respondents often consider the evaluation of the first profiles to be the most difficult. Consequently the observed rating of holdout 2 is only of limited use. If only the observed ratings of holdout 1 are considered, the predictive capability of the estimated models is moderate, considering the range of the related rating scales.

Table 7-9: Model performance on holdout profiles

	predicted value by model	mean observed value	mean absolute difference	standard deviation
Holdout 1 (n=485):				
attractiveness	4.85	5.77	1.87	1.49
comfort	0.81	0.90	0.80	0.64
safety	0.94	0.99	1.18	0.63
Holdout 2 (n=485):				
attractiveness	4.49	5.15	2.60	1.54
comfort	0.10	0.33	1.17	0.99
safety	0.19	0.50	1.24	0.65

7.4 Different preferences of car, bus and truck respondents

Given the aggregate models on the systems' overall attractiveness, comfort and safety, the following step is to study whether different subgroups have different preferences. The procedure to analyse these differences is described in subsection 6.4.5. First, in subsection 7.4.1, the differences between drivers and fleet-operators in general are analysed. Then the differences within the drivers group (car-, bus- and truck drivers) respectively within the fleet-operators group (car-, bus and truck fleet-operators) will be addressed in subsection 7.4.2 and 7.4.3, respectively.

7.4.1 Differences between drivers and fleet-operators

Table 7-10 presents the estimated models on the systems' overall attractiveness, comfort and safety for drivers and fleet-operators. The part-worth utilities that have been found

Table 7-10: Differences between drivers and fleet-operators

attributes	part-worths overall attractiveness		part-worths comfort		part-worths safety	
	drivers	fleet-oper.	drivers	fleet-oper.	drivers	fleet-oper.
<i>distance keeping</i>						
warning	0.30	0.29	0.17	0.12	0.19	0.16
throttle assistance	-0.11	-0.14	-0.05	-0.06	-0.07	-0.13
throttle/brake assistance	-0.19	-0.15	-0.12	-0.06	-0.12	-0.03
<i>lane keeping</i>						
none	-0.15	-0.19	-0.04	-0.09	-0.06	-0.08
warning	0.32	0.29	0.20	0.17	0.22	0.19
steering assistance	-0.17	-0.10	0.16	0.08	-0.16	-0.11
<i>lane changing</i>						
no support	-0.22	-0.15	0.24	-0.04	-0.09	-0.12
warning	0.52	0.30	0.24*	0.14*	0.30*	0.18*
steering assistance	-0.30	-0.15	-0.48	-0.10	-0.21	-0.06
<i>price</i>						
\$500	0.44	0.27	-	-	-	-
\$1000	0.03	0.07	-	-	-	-
\$1500	-0.41	-0.34	-	-	-	-
<i>travel time</i>						
+10%	-0.42	-0.57	-	-	-	-
equal	0.15	0.11	-	-	-	-
-10%	0.27	0.46	-	-	-	-
<i>fuel consumption</i>						
+5%	-0.38	-0.51	-	-	-	-
equal	0.16	0.05	-	-	-	-
-5%	0.22	0.47	-	-	-	-
regression intercept	4.89	4.90	0.43*	0.56*	0.53*	0.64*
n	320	165	320	165	320	165

*indicate that the part-worth utilities are significantly different between the groups

significantly different at 0.05 level are marked with a '*'. Regarding the overall attractiveness, none of the estimated effects between drivers and operators were found to be significant. Consequently the attractiveness model presented in Table 7-7 can be used for both groups. As for comfort and safety, minor differences in the average rating of all systems as well as the part-worth for lane change warning have been found significantly different.

On average, fleet-operators consider the systems somewhat more comfortable and safer than vehicle drivers. The part-worths of lane change warning are slightly lower for fleet-operators than for drivers, both for comfort and for safety. This indicates that drivers consider lane changing warning more comfortable and safer than fleet-operators.

7.4.2 Differences between driver groups

When the different driver groups are analysed more closely, more variety in preferences was found, in particular between car drivers and truck drivers. In Table 7-11 the desaggregate models for car drivers and truck drivers are presented. Those part-worth utilities that have been found significantly different at 0.05 level are marked with a '*'.

Regarding the attractiveness model, the intercept for *car drivers* is 4.80 and for *truck drivers* 5.30. This means that, on average, truck drivers consider the suggested systems to be somewhat more attractive than car drivers. Furthermore, the part-worth for no lane change support is negative for car drivers and positive for truck drivers. This implies that car drivers prefer systems with no lane change support less than truck drivers do. A low price level is preferred more by car drivers than by truck drivers. This is not surprising, knowing that part of the car-driving respondents will have to buy a system on personal account. Furthermore, because trucks are generally more expensive than cars (see average vehicle price levels in Table 7-4), the relative price of a system (in terms of the percentage of the vehicle price) is less for trucks than for cars.

The part-worth for systems causing an increase in fuel consumption with 5% is more than two times as large for truck drivers as for car drivers. Since the fuel consumption for trucks is usually much larger than for cars and consequently 5% more fuel usage affects truck operations much more than car-driving, this also appears to be plausible.

According to truck drivers, systems with distance keeping warning, lane keeping warning and no lane change support are expected to contribute more to their driving comfort as compared to car drivers. Truck drivers consider systems with lane keeping warning more safe.

Between *car drivers* and *bus drivers* (not shown in table) only the average rating of systems on safety has been found significantly different. Car drivers, on average, evaluate the systems somewhat safer than bus drivers do (0.57 versus 0.46).

Between *bus drivers* and *truck drivers* (not shown in table) only the average attractiveness was found to be significantly different. Truck drivers, on average, consider systems more attractive than bus drivers do (5.30 versus 4.80).

In summary, the analysis on differences between the pre-specified driver groups points out that, on average, truck drivers do consider the systems moderately attractive, whereas

car- and bus drivers evaluate the systems more unattractive. In particular, truck drivers prefer systems with no lane change support as well as systems which cause no increase in fuel performance more than car drivers do. A low price level of systems is more preferred by car drivers than by truck drivers.

Table 7-11 Models for car drivers and truck drivers

attributes	part-worths overall attractiveness		part-worths comfort		part-worths safety	
	car drivers	truck drivers	car drivers	truck drivers	car drivers	truck drivers
<i>distance keeping</i>						
warning	0.29	0.37	0.12*	0.32*	0.18	0.24
throttle assistance	-0.16	-0.01	-0.07	-0.01	-0.10	-0.02
throttle/brake assistance	-0.13	-0.36	-0.05	-0.31	-0.08	-0.22
<i>lane keeping</i>						
none	-0.15	-0.12	-0.06	-0.04	-0.08	-0.02
warning	0.28	0.54	0.14*	0.36*	0.19*	0.34*
steering assistance	-0.13	-0.32	-0.08	-0.32	-0.11	-0.32
<i>lane changing</i>						
no support	-0.30*	0.11*	-0.10*	0.08*	-0.12	-0.01
warning	0.56	0.28	0.25	0.21	0.26	0.30
steering assistance	-0.26	-0.39	-0.15	-0.37	-0.38	-0.29
<i>price</i>						
\$500	0.56*	0.18*	-	-	-	-
\$1000	0.11	0.01	-	-	-	-
\$1500	-0.67	-0.19	-	-	-	-
<i>travel time</i>						
+10%	-0.42	-0.31	-	-	-	-
equal	0.12	0.16	-	-	-	-
-10%	0.30	0.15	-	-	-	-
<i>fuel consumption</i>						
+5%	-0.29*	-0.70*	-	-	-	-
equal	0.14	0.38	-	-	-	-
-5%	0.15	0.32	-	-	-	-
regression intercept	4.80*	5.30*	0.44	0.40	0.57	0.48
n	200	59	200	59	200	59

*indicate that the part-worth utilities are significantly different between the groups

7.4.3 Differences between fleet-operator groups

The significant differences in part-worth utilities for *car fleet-operators* and *bus fleet-operators* of separate models are shown in Table 7-12. On average, car fleet-operators evaluate the systems more comfortable, safer and more attractive than bus fleet-operators.

Systems which have no lane keeping support are considered to be to make driving more unsafe by car fleet-operators than by bus fleet-operators.

Table 7-12: Significant differences between car- and bus fleet-operators

attributes	part-worths overall attractiveness		part-worths comfort		part-worths safety	
	car fleet operators	bus fleet operators	car fleet operators	bus fleet operators	car fleet operators	bus fleet operators
<i>lane keeping</i>						
none					-0.24	0.01
regression intercept	5.32	4.56	0.74	0.50	0.86	0.54
n	37	32	37	32	37	32

The differences in preferences between *car fleet-operators* and *truck fleet-operators* are presented in Table 7-13. On average, car fleet-operators evaluate the systems more comfortable, safer and more attractive than truck fleet-operators.

Table 7-13: Significant differences between car- and truck fleet-operators

attributes	part-worths overall attractiveness		part-worths comfort		part-worths safety	
	car fleet operators	truck fleet operators	car fleet operators	truck fleet operators	car fleet operators	truck fleet operators
regression intercept	5.38	4.79	0.74	0.50	0.86	0.58
n	37	96	37	96	37	96

The models for *bus-* and *truck fleet-operators* were almost similar. Only one part-worth has been found significantly different (Table 7-14). On average, bus fleet-operators evaluate the systems to be somewhat less comfortable than truck fleet-operators do (-0.22 versus -0.02).

Table 7-14: Significant differences between bus- and truck fleet-operators

attributes	part-worths overall attractiveness		part-worths comfort		part-worths safety	
	bus fleet operators	truck fleet operators	bus fleet operators	truck fleet operators	bus fleet operators	truck fleet operators
regression intercept	-	-	-0.22	-0.02	-	-
n	32	96	32	96	32	96

Summarising, it appears that car fleet-operators, on average, consider the systems to be moderately attractive whereas truck- and bus fleet-operators consider the systems to be more unattractive.

7.5 Influence of background values on preferences

Finally, the possible influence of some basic characteristics of respondents, as presented in section 7.2, on overall preferences is analysed. The procedure to perform such an analysis is similar to the procedure used in the previous section.

An analysis of the influence of social characteristics of respondents on overall preferences revealed the following. In order to identify the possible influence of *gender*, the respondents were subdivided into the categories male (433 respondents) and female (47 respondents). The estimation of contrast parameters showed no significant differences for the comfort and the safety model. Regarding the overall attractiveness of systems some differences in part-worths were found to be statistically significant. Distance warning and lane changing warning were both evaluated significantly higher by women as compared to men, with 0.23 and 0.21 respectively. So, systems which support distance keeping respectively lane changing by warning are more preferred by women than by men.

In order to analyse the influence of *age* the respondents were divided into two categories: a category of 239 respondents being younger than 40 years of age and a category of 239 respondents being at least 40 years of age. For the comfort, safety and attractiveness model, none of the estimated contrast parameters appeared to be statistically significant. Hence, based on this data, there are, regarding the systems questioned, no differences in preferences of older people as compared to younger people.

In order to study the influence of the level of *education* of the respondents regarding their preferences, a contrast analysis has been performed on two subgroups of respondents. One subgroup contained respondents with an educational level of secondary school or less (273 respondents) and one subgroup contained respondents with at least a bachelor's degree (200 respondents). The analysis revealed no significant contrast parameters for the comfort, safety and attractiveness model. Hence, next to age, also the level of education of the respondents showed no significant influence on their preferences

Finally, the influence of *familiarity* with the systems questioned has been researched. A contrast analysis on the none/moderate-familiar group (381 respondents) and the familiar group (97 respondents) showed, for each preference model, no significant differences between the two groups. Thus, according to our data, the degree to which respondents were familiar with early AVG systems did not influence their opinions

Next to the influence of social characteristics of respondents regarding their preference behaviour, the influence of some vehicle- and trip characteristics of the driver respondents and some fleet- and transport characteristics of the fleet-operator respondents respectively have been analysed as well.

Regarding the influence of the amount of kilometres driven by vehicle drivers and regarding the sizes of fleets of fleet-operators, the following can be reported with regard to their preferences for early AVG systems. In order to analyse whether the *amount of kilometres* driven by vehicle drivers influenced their preference behaviour, the (vehicle) drivers were divided into two categories, each containing 160 respondents. The first category drove more than 800 kilometres a week and the second category drove less than

800 kilometres a week. Contrast analysis pointed out that the drivers who drove many kilometres considered the systems on average somewhat more attractive: the intercept of the estimated model for the drivers who drove more than 800 km a week was found significantly higher (with a value of 0.18) as compared to drivers who drove less than 800 km a week. As for the comfort- and safety preferences, no significant differences were found.

Fleet-operators were subdivided into two categories in order to analyse whether their *fleet size* influenced their preference behaviour: the first category consisted of those fleet-operators who indicated to have a fleet of 25 or less vehicles (87 fleet-operators), and the second category consisted of the fleet-operators with a fleet of more than 25 vehicles (80 fleet-operators). Contrast analysis showed a significant difference of 0.32 for the intercept of the overall attractiveness model in favour of the second category. No differences between these categories were found to be significant for the comfort and the safety model. This implies that fleet-operators with a large fleet prefer the systems more as compared to their colleagues with small fleets.

Finally, the influence of vehicle price and vehicle ownership of car drivers has been researched with regard to their preference behaviour. It is to be expected that car drivers with expensive vehicles will consider the price of systems less important than people with less expensive vehicles. In order to analyse whether the respondents' *vehicle price* influenced their preferences in this study, the car-driving respondents were subdivided into two categories. One category consisted of car-driving respondents with vehicles with a purchase price of 40,000 guilders or less (91 respondents), and the other category consisted of car-driving respondents with a purchase price of more than 40,000 guilders (100 respondents). None of the differences of part-worth utilities between the categories appeared to be significant. The purchase price of the vehicle appears to have no influence on the preferences regarding the systems' overall attractiveness.

In order to study the influence of *vehicle ownership* on the respondents' preferences, the car drivers were subdivided into a category of private drivers (108 respondents) and a category of business drivers (92 respondents). The contrast analysis pointed out that the intercepts of the attractiveness models of the subgroups differed significantly: for private drivers the intercept was found to be 4.28 and for business drivers this was 4.90. Hence, business drivers perceive the systems on average more attractive as compared to private drivers.

7.6 Conclusions

It is often assumed that consumers acceptance on driver support services is totally lacking. On average, drivers and fleet-operators tend to judge the attractiveness of having early AVG systems in their vehicle(s) somewhat unattractive indeed. However, this study shows that this assumption needs to be nuanced. In this study it was found that technical functions of systems are evaluated less important than the costs and benefits of the system. This

might be caused, among others, by the fact that most respondents are unfamiliar with the systems questioned and hence with the technical attributes considered.

The price of a system influences the attractiveness most, which may lead to the conclusion that AVG preference behaviour can be heavily influenced by financial incentives (e.g. government subsidies). Next, systems which negatively influence travel time performance or fuel consumption, lower the overall utility rapidly. This indicates that one should take care of implementing early AVG systems that influence travel time and fuel consumption negatively.

Warning devices with profits on travel time and fuel consumption against a low price are found to be most attractive. Lane changing support is preferred to distance keeping and lane keeping. This is interesting given the level of attention within research and development on distance keeping services. Another remarkable fact is that consumers prefer warning devices for lane keeping and changing to no support or steering assistance. This indicates that it has to be tried to implement systems that warn drivers for each type of support, because this increases the overall utility.

Regarding the estimated comfort and safety model, similar tendencies have been found as for the attractiveness model: respondents prefer warning support to assistance for each technical function and even to no support for lane keeping and lane changing. Hence, like the evaluated attractiveness, driving comfort and safety also point at the direction of focussing at the implementation of warning devices.

In general, the attractiveness of systems is evaluated equally by both drivers and operators. Vehicle drivers consider lane change warning systems more safe and more comfortable than fleet-operators.

Considering the pre-specified consumer groups, it was found that truck drivers and car fleet-operators respectively, on average, consider AVG systems more attractive than the other driver groups and other fleet-operator groups respectively. Hence, regarding implementation of AVG systems these groups can be considered as initial target groups for implementation. Furthermore, considering only car drivers, business drivers evaluate the systems more attractive than private drivers. So, in addition to truck drivers and car fleet-operators, business drivers might be considered to be an interesting market for initial implementation as well. Hence, the business-car market is promising in terms of recommendations for implementation strategies. As for the truck market, truck operators consider AVG systems moderately unattractive and as such might be reluctant to the implementation of early AVG systems.

Some measures of model performance have been discussed during the presentation of the models, in particular the significance of t-values and anticipated directions of part-worth utilities. These measures show no surprises with regard to the cost-benefit attributes as all increases in price, travel time and fuel performance show decreasing tendencies. However, regarding the technical attributes unanticipated optima have been found for lane keeping and lane changing.

The explained variance of the estimated models indicated that large differences exist between the evaluations of individual respondents and consequently the predictive validity,

measured by the models' ability to predict the individual scores of holdout profiles, was moderate. Whether these differences could be explained by differences in the background characteristics of consumer groups appeared only limited to be the case. Although not reported, the explained variance did not increase significantly if the utility function was broken down by these characteristics. Hence, the non-representativeness of the respondents according to these characteristics are hardly of influence on their overt preference behaviour. Furthermore, the part-worth utilities, reported in this paper could be interpreted well, which gives face validity to the estimated preference models.

Overall, the conjoint approach appears to be a useful tool to examine consumers' preferences for innovative transport technologies. In future research the usefulness of this approach will be studied further.

Chapter 8.

Conclusions and discussion

8.1 Introduction

In this thesis the complexity of the implementation of AVG from the perspective of public policy decision making has been studied. On the one hand several studies and pilots have pointed out that AVG technologies have a high potential in terms of contributing to general transport policy goals, on the other hand, public policy and decision making is confronted with the existence of large uncertainty on future AVG development and implementation. The challenge has been to develop an innovative approach to identify and reduce this uncertainty. In this chapter the main research results are presented, discussed and synthesised. In particular in section 8.2, some reflection is given on the specified approach and techniques used throughout this thesis. Next, section 8.3 focuses on the main findings regarding the identification and reduction of uncertainty. Finally, in section 8.4, the implications of these findings are translated into recommendations for public policy making.

8.2 Methodological findings

This thesis aims at the specification, operationalisation and application of an innovative technology assessment approach to identify and reduce the uncertainty of future AVG implementation. In order to realise this research objective, we addressed the following research questions:

1. *What methodological approach can be based upon the field of TA to cope with the uncertainties regarding future AVG implementation?*
2. *(a) How can the long-term uncertainties be better structured in order to allow for more in-depth analysis of plausible developments for the medium term (up to 2020/2025)? (b) What are the results of this analysis?*
3. *(a) How can conditions of plausible technology applications for this time period be analysed in-depth? (b) What are the results of this analysis?*
4. *(a) How can the likeliness of these developments be explored, from the perspective of crucial stakeholders, for a successful, near-term implementation? (b) What are the results of this analysis?*
5. *What conclusions can be drawn with regard to the role of public authorities in relation to AVG development?*

This section focuses on the methodological part of the research questions (research question 1, 2a, 3a and 4a). As indicated in section 2.2, the methodological approach of a TA can be defined in terms of assessment methodologies and methods. The methods used within a TA aim at studying a specific aspect related to the TA problem and the assessment methodologies aim at integrating the different aspects of the technology studied and/or the decision process to be addressed.

Regarding the first research question, the research field of TA has been considered to be of natural interest in this context as, in general, TA focuses on how to influence the course of future technology developments in a societal desired direction. In Chapter 2 it appeared that the field of TA is large and diverse in terms of problem areas applied, the TA styles used (Awareness, Strategic and Constructive TA), the methodologies used for study and the methods used within the TA. This is both an advantage and a disadvantage for research. An advantage in the sense that TA offers a broad, flexible framework within which choices can be made which seem most appropriate for the subject of study. A disadvantage in the sense that most TA studies have been performed in practice and were found to be typically problem-driven. Few researchers do reflect on their choices made regarding the general methodology for their TA study and the specific methods used within their TA study. Hence, hard scientific criteria for choices are lacking in this context and the researcher is forced to make her/his own choices. As such, the TA practitioner is confronted with a typical TA problem for research on the one hand, and a variety of possible TA styles and possible methodological approaches on the other hand.

As long as criteria for choices are not available, the logical research strategy to follow is to first structure and limit the subject of study. Without structure and limitations, the degrees of freedom are too numerous and too substantial to set up a TA study and to apply research methods in an effective way. The issue of AVG implementation has been structured and limited using a system view on AVG and the transport system. This implied the need for a research approach which links information on the physical performance of AVG implementation with the related decisions and actions needed to achieve this performance.

Such approach has been specified in Chapter 2. It is based on backcasting analysis, focusing on the physical conditions to be assumed with respect to implementing particular AVG concepts and with respect to the likeliness that stakeholders are willing to support the implementation of these concepts. The result of this backcasting is the elimination of non-plausible and non-accepted AVG concepts and the reduction of the scope to the most promising ones.

The conceptual approach developed within this thesis differs significantly from most other TA exercises in the field of AVG (and transport telematics in general). Most of these studies roughly follow the line from studying different aspects of sophisticated AVG systems in-depth (e.g. traffic impacts, cost-benefits, etc.), sometimes gradually broadening the scope to studying those aspects which appear to be relevant throughout the research process. In contrast, within this thesis an approach is followed which explicitly starts from a broad view, making attempts to incorporate all possible aspects which might be relevant to implementation and limiting the scope throughout the research process by focusing on the conditions assumed for implementation. Each approach has its advantages and disadvantages.

The first approach logically results in more, often quantified findings on each aspect studied. Furthermore, one can often rely on a set of well-proven sophisticated, research methodologies and methods. However, due to the isolated treatment of the aspects, the real-world validity of the research findings can be discussed. Furthermore, some aspects might be overlooked as they are of no interest at the moment of study or cannot be studied by the techniques available.

An attempt to avoid these disadvantages is made by means of the conceptual approach as presented in this thesis. In contrast, it is tried to identify and assess all aspects which might be relevant, based on an integrated, overall view on the subject of study. Consequently, however, it is often not possible to assess each aspect as thoroughly as in the first approach. Furthermore, as stated earlier, there is no specific protocol on how to perform such an analysis or how to choose the set of methods adequate for this type of study. One is forced to use the more traditional TA methods, although these methods have often been developed for other purposes, and/or to make use of methodologies as developed in other research fields, related to the aims of study.

For instance, the Delphi method has been widely used to forecast the future of a technology in terms of predicting the moments of market introduction or, in addition, even some degrees of market penetration. In this thesis the Delphi method has been used to

identify and assess the conditions for implementation of a technology. Furthermore, the Delphi study was not oriented to getting consensus among experts but to identifying the underlying reasons for diverging opinions.

Conjoint analysis does (even) not belong to the research field of TA, although it might be considered as an extension of the policy capture method by which the preferences of stakeholders involved regarding alternatives are elicited and modelled in a similar way. Conjoint analysis is often used to predict consumers' future preference and choice behaviour. We used the conjoint analysis as a tool to get insight into the preferences of early adopters regarding AVG as well as into the relationship between AVG alternatives and potential attractiveness.

Ideally, in case of large uncertainty with regard to both the technological progress and the organisational process of technology implementation, one should perform a TA study using both approaches, as both separate approaches have their limitations. In this way a maximum insight into all relevant aspects of technology implementation can be obtained. Such a complementary approach characterises the research programme 'Technology Assessment on Automated Vehicle Guidance' (see section 1.2), of which the research performed in this thesis forms part of. The other three PhD projects in this programme have been studying implementation of AVG at the specific levels of, respectively, driver- and travel behaviour, traffic performance and infrastructure design, and legislation and tort liability.

However, in practice the assessor will often be forced to choose either the first or the second approach, in particular due to limited resources. If so, the second approach should precede the first. This will limit the scope of the assessment to valid proportions which can be used for follow-up, in-depth research.

Apart from contributing to the insights into the contents of AVG developments, the different research methods used within this thesis have also given some valuable, methodological insights.

Regarding the methodological part of the second research question (question 2a), it has been shown that morphological analysis provides a practical tool to structure and scan future alternative technological concepts. This technique is particularly useful in the phase of problem exploration and problem bounding within a TA. However, it requires some knowledge in advance of the technology studied. This is needed to appropriately identify all the key dimensions as well as their possible values underlying the alternative concepts. Furthermore, the judgement of the plausibility of alternatives needs to be done carefully as one could, at first sight, exclude concepts which might appear to be plausible after all due to for instance accelerated technological progress, new insights, etc. Therefore, in case of hesitation, such concepts should not be excluded.

The opinions of experts have been used to analyse plausible developments of AVG in-depth (research question 3a). We already reflected on the pros and cons of the Delphi method to gather expert opinions in chapter 4. In summary, the disadvantages of the Delphi method are typically related to the aims and the set-up of the study. If one tries to forecast the market introduction of future technologies, focusing on reaching consensus among

experts, the results might be disappointing. Instead, the opinions of experts might be more useful to identify and evaluate barriers to technology implementation, as well as to research underlying reasons for different opinions. A problem is the limited number of experts usually included in a Delphi study, and therefore not enabling for statistical grounding of the arguments. Furthermore, in this thesis it has been argued that the degree of consensus on aggregate level might be misleading as a stopping criterion for the number of rounds. Instead, one should focus on the individual stability of expert opinions over different rounds.

The last methodological issue of the research questions to be answered involved the way in which to explore the likeliness of AVG developments, from the perspective of crucial stakeholders, for a successful, near-term implementation (research question 4a). Conjoint modelling provides a coherent view on evaluation of alternatives and decision making and a well-developed set of research tools is available for the operationalisation of this view. Furthermore, this approach has proven to perform well in terms of predicting preference and choice behaviour in several areas. However, also some limitations of conjoint modelling turned up might have a more general meaning. The set-up of a conjoint measurement requires a considerable amount of research in advance, in particular when this method is used to explore future behaviour regarding highly innovative products or services. Furthermore, although the set-up of the conjoint measurement task is well described in clear, consecutive steps, there are some trade-offs left within each step, for which the researcher basically has to rely on empirical experiences with the method in other fields. Finally, this method has been used mostly to elicit preference and choice behaviour regarding alternatives which can be imagined rather easily by respondents. Hence, for highly innovative products, as in the case of the AVG systems questioned, one should take care that the alternatives are clearly and unambiguously defined for the respondents. A clear presentation is essential for understanding, distinguishing and judging alternatives in a reliable way, that is: resembles their real world behaviour as much as possible. If possible, some visual support (pictures or video) or even prototype products might be of use.

Finally, the problem of lacking scientific knowledge to specify, operationalise and apply a TA approach has been addressed widely throughout this thesis. Therefore, more reflective research is recommended in the field of TA, in terms of comparative assessments using different methodological approaches. This should provide TA researchers with generic, scientific criteria, which can be used when setting up a TA study and choosing particular methods to perform particular steps within the study.

8.3 The reduction of uncertainty regarding future AVG implementation

The research has resulted in the identification and reduction of uncertainty regarding the future implementation of AVG. In this section the results of the application of the specified approach are discussed.

The first step in research involved structuring the variety of possible AVG concepts which might be implemented in the future. In chapter 3 we explored whether this variety can

be structured and reduced to proportions which allow follow-up in-depth research (research question 2b).

It appears that a considerable reduction can be made by eliminating implausible AVG concepts, i.e. concepts which are unlikely to contribute to general transport policy goals and/or are infeasible from a technical or societal point of view. Furthermore, the temporal dimension of these concepts has been analysed in terms of which plausible AVG concepts are likely to be implemented in succession and for which concepts this is not so certain. By applying this temporal dimension, seven groups of plausible, evolving AVG concepts have been defined, based on different functionalities and different levels of automation. Basically, the future implementation of these concepts depends upon the assumption one has on the nature of how these functionalities and levels of automation will develop in the future. Assuming, for instance, that the implementation of the concepts will follow, an evolutionary pattern implies that the implementation of AVG concepts will start with the introduction of informing and assisting intelligence in vehicles, either for longitudinal or lateral support, functioning in a situation characterised by a mix of equipped and non-equipped vehicles, and of use on motorways only. Later on, systems might also become available which are applicable on the underlying road network. Furthermore, dedicated lanes could be constructed on (initially major) motorways for specific groups, enabling improved performance of assisting AVG concepts for both longitudinal and lateral support, followed by the implementation of concepts which enable fully automated driving. This evolutionary perspective is widely accepted and used, either implicitly or explicitly within the AVG research field.

However, in this thesis it has been argued that a more revolutionary development should not be excluded beforehand. The development could start with the implementation of highly automated devices in vehicles and infrastructure, for both longitudinal and lateral support, functioning on dedicated lanes for target groups only, which evolve in time within the road network.

The defined basic key dimensions, the possible values and the elimination procedure of future AVG concepts appeared to be robust throughout this thesis and have been supportive as a general framework to position the large variety of possible concepts. In future research these concepts can now be specified more in-depth as dimensions and values have been assessed throughout this thesis. This enables more detailed, operational definitions of alternative AVG concepts which, in turn, support an analytical evaluation scheme using quantitative measures. Such evaluations should be used to eliminate further implausible concepts and to analyse plausible concepts on their contribution to general transport policy goals as well as on their technical and societal feasibility.

In this thesis the theoretical assumption that the implementation of AVG concepts is likely to take place in an evolutionary way has only been limited confirmed. In particular, it can be concluded that the rigid, evolutionary perspective often developed within the research on implementation strategies towards fully automated driving or Automated Highway Systems (AHS) is not as obvious as often stated. These studies differ from the research performed in this thesis, simply because there is clearly defined final view, e.g. an

AHS, and different roads towards this goal are assessed. These roads are mainly based on assumed technological progress in time. As such, within these studies, an evolutionary development is often assumed by which consecutively systems are introduced with increased functionalities and increased level of driving automation. This should enable AVG suppliers to solve the technical problems of today's AHS systems and allow future AHS adopters to become acquainted with an increased automation of vehicle driving tasks. Based on the research findings in this thesis the likeliness that such an evolution will succeed in the future appears not to be proven. There are still several barriers to be dealt with, before such an evolution, if ever, will become reality.

By analysing the plausibility of the specified technology applications more in-depth (first part of research question 3b) it appears that only the (further) introduction of various warning devices for driving support as well as vehicle-following systems with limited deceleration capabilities is most certain on the short-term. Although, in the longer run (2005-2020), the introduction of systems is expected which take temporary control of the vehicle in case of dangerous situations with more general obstacles and/or assist the driver in case of impending road departure, it is anything but certain that these systems will further evolve. Technological progress, improved consumer acceptance and the adaptation of legislation are central problems for the future implementation of more advanced systems. Furthermore, these systems are initially expected to be marketed for specific groups and to be of use on motorways only. However, this is the point to which the evolution has been confirmed in this study. A further evolution in terms of a likely majority of the vehicle driving population using AVG systems applicable on secondary roads seems far away. Furthermore, the implementation of further automation in the next decades, up to the level of the autopilot, appeared, more than generally expected, highly uncertain. The feasibility of various technical as well as non-technical conditions under which the implementation of this new transport mode can be achieved, is considered to be highly uncertain.

As such, it is unlikely to assume that the implementation of AVG will contribute significantly to general transport policy goals in the next two decades. Although, systems which support part of the driving task are considered rather certain to improve traffic safety, their limited use by specific driver groups on the most safe types of roads (motorways) will only give limited safety impacts. Research towards technologies which enable both a reliable and an accurate detection and recognition of more general obstacles than only vehicles remains required, in order to stimulate the application of systems at lower road networks. Although a serious research effort has been made in this field over the past years, this still appears to be one of the most challenging issues within the field of AVG system design. Next to in-vehicle sensing options, more attention should be given to solutions which are based on communication between vehicles and/or roadways. These solutions do reduce the huge performance claims regarding stand-alone, in-vehicle sensors. Furthermore, it is uncertain how drivers will adapt their driving behaviour in terms of, for instance, lower alertness or increased driving speed. These mechanisms could countermeasure initial safety benefits. Hence, (more) research is recommended to identify

and analyse these mechanisms and search for measures to prevent drivers from such behaviour.

The contribution to other policy goals of systems which support part of the vehicle driving task, in particular to improved road efficiency and to a reduction of environmental stress, is unlikely or might even be negative. Such contributions are now only achieved under severe conditions assuming uniform vehicle systems with short time headways, dedicated lanes, high penetration degrees, optimal system- and road conditions, proper use, etc. It is not expected that these conditions will be met in the short- or medium term. Only the full automation of vehicle driving tasks, i.e. the autopilot, has been evaluated to be a potential contributor regarding increased road capacity and reduction of environmental impacts. However, several technical and non-technical issues need to be solved before this concept can be implemented on public roads.

Hence, as there is still a long way to go before advanced AVG systems can be implemented on a large scale, the focus should nowadays be more on successes of implementation in the short term. Hence, the question is what can be reached in the near future. It implies a shift in attention from systems which fully automate the total vehicle driving task to systems which only support part of the driving task by information or limited control. In the US such a shift has recently occurred. After years of research on the AHS, the current focus is now on applications for the near future (Intelligent Vehicle Initiative).

In the short term, AVG implementation is expected to be determined by market opportunities (research question 4b). Particularly, the preferences and choices of consumers will be the main critical factors behind implementation of early AVG systems. On average, drivers and fleet-operators evaluate early AVG systems to be somewhat unattractive to have in their vehicle. However, the attractiveness of AVG systems appears to depend strongly on the degree of support a system initiates in case of collision risks, the system price and the influence of the system on travel time and fuel consumption. The price of a system dominates the attractiveness most. Hence, the relatively high system price of current devices is likely to discourage people from purchasing these systems. Furthermore, systems which influence travel time and fuel consumption negatively, lower the overall attractiveness rapidly. Regarding the different types of support or functionalities, lane changing support is preferred to distance keeping and lane keeping respectively. In particular lane changing support is perceived to be more comfortable and safer as compared to the other types of support. This is in contrast with the fact that lane keeping systems could contribute to the reduction of fatalities and injuries on motorways most, closely followed by distance keeping. Accident statistics point out that lane change support has only limited potential on these roads. Furthermore, warning devices are preferred to systems taking temporary control. Furthermore, systems which support lane keeping and lane changing by warning are preferred to systems which do not support or intervene by steering assistance. Apparently, there is a need for lateral (warning) support among consumers. This conflicts with the technological developments which has mostly been focusing on longitudinal support.

When considering different consumer groups, truck drivers and car fleet-operators seem, on average, to consider AVG systems to be more attractive than other driver groups and fleet-operators respectively. Hence, these groups can be regarded as initial target groups for implementation of early AVG systems. Furthermore, when considering only car drivers, business drivers evaluate the systems more attractive than private drivers. So, in addition, also business drivers might be considered an interesting market for initial implementation.

8.4 Recommendations for public policy making

Given the findings of this study, we are now able to deal with the last research question addressed in this thesis, involving what policy measures can and should be taken in the near future in order to deal with the findings of our research. Of course, most findings cannot be translated directly into some policy measures. Nevertheless, some future policy actions are highly recommendable in order to guide further developments of AVG into a societal desired way.

Although policy programmes can hardly influence the more technical development of AVG, a continuation of further management of AVG research and development is considered important. However, the goals of this research and development should be adjusted from the design and testing of technological sophisticated AVG systems on their intended impacts within controlled experiments towards constructing AVG concepts which are useful and desired from a societal point of view. For instance, research should be stimulated towards AVG technologies which contribute to traffic safety on lower road levels and which support drivers regarding conflicts with slow-traffic participants. Regarding traffic efficiency, the autopilot has only in theory high potential to solve the congestion problem in the near future. Only advanced automation of particular groups (e.g. truck drivers) on dedicated lanes might be an option in this context. Hence, this implies researching the possibilities for implementation of advanced automation concepts in relation to the desires of these specific groups.

In the previous section we argued the contribution of most support systems to road capacity gains and reduction of environmental impacts to be uncertain. Driving convenience and individual driving safety are expected to be the critical factors for market introduction. However, safety improvements are strictly limited to driving situations the system is designed for and could easily be countermeasured by more risky driving behaviour. Furthermore, for each type of support several systems are expected to become available with different operating characteristics. The way in which this diversity will affect total traffic performances is unclear.

Public authorities have the responsibility to specify system performance indicators and values, and to translate them into rules these systems should meet in order to avoid negative impacts on overall traffic flow efficiency and safety. This would give more direction to the technical elaboration of these systems.

Consider for instance speed headway support with deceleration capabilities. This type of support is becoming available nowadays. A range of system-setting requirements should be

specified concerning the headway according to which both safety conditions (e.g. the largest headway which does not affect the traffic efficiency negatively) and efficiency/environment conditions are satisfied (e.g. the shortest headway which does not increase the collision risk probability). Such settings are currently researched (e.g. ASHRA, 1998).

Also, today's legislation on liability needs attention to be able to deal with the possible consequences of more intervening systems, for instance front and side obstacle avoidance systems. Evidently, the provision of adequate legislation is the task of public bodies. In Japan and the US, the design and approval of such legislation is likely to be less difficult than in Europe where legislation is not uniform across different countries. Due to this, market introduction of more sophisticated AVG systems in Europe could be postponed. However, concerns about liability exposure of developers and vendors of systems in the US could also delay introduction onto this market. The current lack of transparency in legal regulations should be solved, as this leads to hesitating stakeholders and, due to this delay, the development and implementation of systems developed with high R&D costs.

Next to stimulating research and providing regulations and legislation, public authorities should consider to become more involved as AVG implementator in the future. We already argued that inter-vehicle and vehicle-road communication is likely to improve system performance and accelerate the introduction of more advanced systems. Furthermore, with respect to lane keeping some infrastructure facilities might be necessary, depending on the type of key technology used. Even the construction of dedicated lanes and provision of roadway instrumentation is considered to be highly important to the autopilot only. Whether some infrastructure facilities are necessary for lane keeping, depends on the type of key technology used.

Finally, the acceptance of potential users of AVG should be improved. It is important to put effort into informing and educating the potential users of the systems. Information is essential for support and for successful marketing. Consumers could be educated with regard to the potential as well as with regard to the risks of AVG. This should support consumers to interpret and evaluate AVG in a proper way. Such education could be performed in several ways including demonstrations, pilots, strategic niche management, etc. Professional road users could serve as initial target groups for implementation of AVG. The adoption of AVG technologies by these consumers likely requires stimulating measures according to their specific needs and preferences. Next to financial incentives, one could think of stimulating the implementation of systems which does not affect fuel consumption and travel time in a negative way, support drivers by warning instead of controlling, etc.

Summarising, a more active public policy making in the context of AVG implementation can and should be undertaken in a number of ways. We hope that our research will support the development of the current and future policy strategy of public bodies.

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Appendix A.

The Delphi study

In this Appendix the questions, expert-panel and analysis with regard to the Delphi study are presented. In section A.1 the full questionnaire is presented. The experts who indicated that their name could be mentioned in this study are given in section A.2. In section A.3 the results of an analysis regarding the stability of the expert opinions over consecutive rounds are presented. Finally section A.4 presents the results of concordance analyses applied to each set of barriers questioned in the study.

A.1 The questionnaire

In this section the questionnaire is presented, which has been used within the Delphi to elicit the opinions of the experts. Consecutively the accompanying letter, the survey explanation, the recommended experts form and questionnaire are presented.

The accompanying letter

Dear Mr/Mrs. Expert,

With this letter, we would kindly request that you to fill out the attached questionnaire. We are conducting a Delphi survey to assess the future expectations of driver support systems for large scale, real world applications. We are particularly interested in the various driving forces and barriers for the implementation of these systems. This Delphi survey is part of an *independent* PhD research.

The success of this survey depends on the cooperation of experts in the field of driver support technologies. We therefore have selected you to participate in our study. Expertise in all of the areas included in the survey is not expected nor required. So far, we have invited about 100 experts worldwide, working within automotive and electronic industries, research institutes, and public authorities. In order to a guarantee a complete expert panel we ask you kindly to forward us three names of the main experts you know in this field, using the form enclosed. If they are not already selected, they will be included in our survey also.

We understand that your time is precious, therefore we have tried to limit the questionnaire. Furthermore, if you participate, *we will send you a full report on the results of this Delphi*. This report will present a valuable overview of future driver support developments that might be relevant to your specific interests. *Your response will be handled anonymously and with confidentiality*. If you wish however, your name and affiliation can be included on a separate list, to be attached to the report.

Please return the questionnaire before the first of June as well as the form with personal data. If you have any questions or suggestions you would like to discuss, please call or mail Vincent Marchau. We kindly thank you in advance for your cooperation.

Yours sincerely,
Vincent Marchau, Ph.D. researcher
Rob van der Heijden, Professor in Transport Policy.

Survey explanation

Early 1995 the research programme 'Technology Assessment on Automated Vehicle Guidance' started within the Dutch Research School TRANsport, Infrastructure and Logistics (TRAIL). At present, the programme consists of four interdependent PhD. projects in which implementation problems of driver support systems are studied at the levels of respectively driver and travel behaviour, traffic performance and infrastructure design, legislation and tort liability, and public policy and decision making. This survey is related to the latter project. The results of the survey will be used for modelling future preferences, choice behaviour and decision making of parties involved in implementation of driver support systems on a large scale.

The Delphi method consists of a series of repeated interrogations, using questionnaires, of a group of individuals whose opinions or judgements are of interest. After an initial interrogation of all individuals, a feedback is given to the respondents. Each subsequent interrogation is accompanied by information collected in the previous interrogations, presented anonymously. Respondents are thus encouraged to reconsider and, if appropriate, to change their earlier replies considering replies of other members of the group. After two or three rounds, the group position(s) is, are determined. The method is usually conducted via paper and mail and was originally developed at the RAND Corporation by Olaf Helmer and Norman Dalkey.

This Delphi survey is aiming at the identification and exploration of future driver support systems. Although some systems are currently implemented on a small scale, we are interested in opportunities of implementation on a large scale applicability, as this could contribute significantly to public policy goals. More particular, the survey is aimed at clarifying:

- the expected period of introduction of a specific support system;
- the expected scale of application during the first period after introduction;
- today's barriers which obstruct introduction and/or further developments;

The following types of driver support systems are questioned in depth in the questionnaire:

- SHK = speed headway keeping: this system detects the preceding vehicle and support a driver by maintaining a correct distance between the vehicles (e.g. adaptive cruise control);
- FCAS = front obstacle collision avoidance: the driver is warned and/or the vehicle temporarily automatically controlled in case of a potential collision with a moving or stationary front obstacle;
- LKS = lane keeping support: this system warns a driver and/or controls the vehicle temporarily in case of impending road departure;

- SCAS = side obstacle collision avoidance: the driver is warned and/or the vehicle is temporarily automatically controlled in case of collision danger during lane changing and merging;
- AP = autopilot: all driving tasks are fully automated by this system, allowing 'hand-off' and 'feet-off' driving.

Recommended experts form

We would be very pleased in case you could forward us the names of three other experts you know as soon as possible. You can use this form and fax it to Vincent Marchau at +31 15 278 8547 or send an email to vincentm@sepa.tudelft.nl

Expert:	
name:	.....
institute:	.....
address:	.....
country:	.....

Expert:	
name:	.....
institute:	.....
address:	.....
country:	.....

Expert:	
name:	.....
institute:	.....
address:	.....
country:	.....

The questionnaire

Please return the complete questionnaire before the first of June to Vincent Marchau. If possible by fax: +31 15 278 8547

Question 1: Could you indicate to what degree you are an expert on each system?

	SHK	FCAS	LKS	SCAS	AP
major. i.e. specialist/expert	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
average. i.e. read a lot and/or done minor research	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
minor. i.e. read about system in technical literature	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
no special expertise. i.e. newspaper knowledge	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Question 2: In which time interval do you estimate the commercial availability/market introduction of each system? Except for the autopilot, for most systems a difference can be made between the degree of control they initiate. In particular, we are interested whether there will be a time lag between the commercial availability of warning only devices and systems which do take temporarily control. If you think there will be a time lag, please indicate so at the table.

systems	SHK	FCAS	LKS	SCAS	AP
time interval					
	warn-control	warn-control	warn-control	warn-control	
(1) before 2000	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(2) 2000-2005	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(3) 2005-2010	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(4) 2010-2020	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(5) 2020	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(6) never	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(7) no opinion	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>

Question 3: Considering your time estimates in question 2, in which cost interval do you estimate the net consumer costs of each system? Again, if you think a difference is possible between warning only devices and systems which intervene the driver actively, please indicate so at the table.

systems	SHK	FCAS	LKS	SCAS	AP
user costs					
	warn-control	warn-control	warn-control	warn-control	
(1) less then \$500	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(2) \$500 - \$1000	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(3) \$1000 - \$1500	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(4) \$1500 - \$2500	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(5) \$2500 - \$5000	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(6) over \$5000	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>
(7) no opinion	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	<input type="radio"/>

Question 4: Please indicate which type(s) of roads are most appropriate for initial implementation, i.e. during the first 5 years after market introduction. More options are possible!

systems	SHK	FCAS	LKS	SCAS	AP
road types					
dedicated lanes (equipped vehicles only)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
rural motorways (low traffic densities)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
urban motorways (congested areas)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
rural roads (no crash barriers, grade crossings, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
urban roads (presence of pedestrians, bicycles, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
no opinion	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Question 5: Please indicate for which market(s) the system will become available initially, i.e. during the first 5 years after market introduction. More options are possible!

systems	SHK	FCAS	LKS	SCAS	AP
user groups					
commercial freight operators	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
commuters	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
leisure/recreational drivers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
business drivers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
other groups (please specify):.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
other groups (please specify):.....	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
no opinion	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Question 6: Please indicate to what degree each of the following system goals are still too uncertain for implementation and/or further developments on larger scale: 1= highly uncertain; 2 = uncertain; 3 = moderate certain; 4 = certain; 5 = highly certain (if you have no opinion, please do not tick a box).

systems	SHK	FCAS	LKS	SCAS	AP
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
user groups					
reduction of fatal accidents	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
reduction of accident severity	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
increase of road capacity	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
increased driving convenience	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
reduction of environmental impacts	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0

Question 7: Please indicate to what degree each of the following technical barriers will have to be further improved to provide the systems' market introduction and/or further development: 1 = very important barrier; 2 = important barrier; 3 = moderate-important barrier; 4 = unimportant barrier; 5 = very unimportant barriers (if you have no opinion, please do not tick a box). If you have additional barriers please specify at the table.

systems	SHK	FCAS	LKS	SCAS	AP
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
technical barriers					
reliability: system doesn't support when expected	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
accuracy: system doesn't support in the right way	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
danger of interference with other in-car systems	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
parameter trade-off for safety, efficiency and comfort	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
complexity decision making algorithms (steering vs braking)	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
round 1 suggestion: software safety verification	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
round 1 suggestion: technical durability	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0

Question 8: Please indicate to what degree each of the following driving barriers will have to be further improved to provide the systems' market introduction and/or further development: 1 = very important barrier; 2 = important barrier; 3 = moderate-important barrier; 4 = unimportant barrier; 5 = very unimportant barriers (if you have no opinion, please do not tick a box). If you have additional driving barriers please specify at the table.

systems	SHK	FCAS	LKS	SCAS	AP
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
driving barriers	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
possible counteracting driving behaviour	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
possible increase in driver workload	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
possible decrease in driver workload	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
danger of losing driving skills	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
round 1 suggestion: lack of driver education	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0

Question 9: Please indicate to what degree each of the following general barriers could obstruct the systems' introduction and/or further development: 1 = very important barrier; 2 = important barrier; 3 = moderate-important barrier; 4 = unimportant barrier; 5 = very unimportant barriers (if you have no opinion, please do not tick a box). If you have additional barriers please specify at the table.

systems	SHK	FCAS	LKS	SCAS	AP
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
general barriers	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
purchase costs for the consumer	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
consumers perception of system utility	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
costs to public authorities for infrastructural adaptations	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
liability allocation to users. producers. road-owners unclear	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
limited road network applicability of system use	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
international system standardisation difficult to overcome	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
round 1 suggestion: consumers privacy	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0

Question 10: Please describe, or give reference to, the basic technical characteristics of those systems which you expect to be available on a short term (i.e. before 2005 in question 2). This will support a more adequate interpretation of your answers given in relation to other experts opinions.

.....

Question 11: In case you missed essential elements in the questionnaire or in case you have other remarks, please specify here:

.....

Personal Questions:

name:.....
 age:..... sex: m/f
 fax number:.....
 email:.....
 address to be used next time:
 professional training:

Professional status

affiliation:.....
 total number of employees of organisation:.....
 profession/function: researcher / designer / production / engineer / marketer / planner / executive
 other function:.....
 number of employees under your supervision:.....

A.2 Participants within the Delphi study

The Delphi study would not have been possible without the cooperation of fifty experts in the field of AVG systems. The following experts indicated that their name could be mentioned in this study:

- S. Andrews, Toyota Motor Corporation, R&D Planning division - ITS Program Office, Toyota City, Aichi, Japan.
- B. van Arem, TNO - Institute for Infrastructure, Transport & Regional Development, Delft, The Netherlands.
- T. Benz, Benz Consult GmbH, Kalsruhe, Germany.

J.R. Bishop, USDOT, Federal Highway Administration, Turner-Fairbank Highway Research Center Georgetown Pike Mclean VA, USA.

K.A. Brookhuis, University of Groningen, Faculty of Behavioural and Social Sciences, Environmental and Traffic Psychology, Groningen, The Netherlands.

J. Broughton, Transport Research Laboratory, Safety and Environment Resource Centre, Crowthorne Berks, United Kingdom.

A.L. Burgett, USDOT, National Highway Traffic Safety Administration, Washington DC, USA.

P. Carrea, Fiat Research Center, Orbassano (TO), Italy.

A. Chachich, Massachusetts Institute of Technology, Center for Transportation Studies, Cambridge MA, USA.

M. Coemet, Ministry of Transport, Public Works & Water Management, Transport Research Centre, Rotterdam, The Netherlands.

S. Fairclough, HUSAT Reseach Institute, Loughborough, United Kingdom.

U. Franke, Daimler Benz AG, Dept. F1M/IA, Stuttgart, Germany.

F. Garcia-Benitez, University of Sevilla, School of Engineering, Sevilla, Spain.

A. Kuehnle, Dalarna University, Centre for Research on Transportation and Society, Borlange, Sweden.

G. Lind, Transek AB, Solna, Sweden.

P. Miltenburg, Ministry of Transport, Public Works & Water Management, Transport Research Centre, Rotterdam, The Netherlands.

M. Nakamura, Ministry of Construction, Public Works Research Institute - Road Dept, Tsukuba-shi, Ibaraki-ken, Japan.

C.O. Nwagboso, Bolton Institute, Vehicle Systems Research Centre, Bolton, United Kingdom.

M. Rombaut, University of Troyes, Laboratory LM2S, Troyes, France.

S. Smulders, AGV, Nieuwegein, The Netherlands.

C. Thorpe, Carnegie Mellon University, Robotics Institute, Pittsburg PA, USA.

S. Tsugawa, Ministry of International Trade & Industry, Machine Intelligence Division - Mechanical Engineering Lab., Tsukuba-shi, Ibaraki-ken, Japan.

N.J. Ward, University of Leeds, Department of Psychology, Leeds, United Kingdom.

C. Witziers, TNO - Road Vehicles Research Institute, Delft, The Netherlands.

Another twenty-six experts preferred to remain anonymous or didn't indicate their preference in this respect.

A.3 Stability analysis of expert opinions

In this section the stability indices for the individual opinions over consecutive Delphi rounds as discussed in subsection 4.5.1. Given the collected response frequencies over the first two rounds the stability index, λ_B , has been calculated for each issue, with (see formula 4.2):

$$\lambda_B = \frac{\sum_j \max_i f_{jk} - \max_i f_{i,k}}{n - \max_i f_{i,k}}$$

where,

f_{jk} = number of respondents who voted for the j -th response interval in round i but voted for the k -th response interval in round $i+1$

$\max_i f_j$ = highest frequency for the j -th response interval at the i -th round

$\max_i f_{i,k}$ = highest total frequency for among the k -th response intervals at round $i+1$

n = total observed frequencies

The calculated indices are presented in Table A-1 and Table A-2.

Table A-1: Stability indices of expert opinions regarding early markets of AVG concepts ($n=50$)

system characteristics	SHK		FCAS		LKS		SCAS		AP
	warn	control	warn	control	warn	control	warn	control	
introduction period	1.00	0.76	0.87	0.85	0.62	0.87	0.84	0.93	0.93
initial user costs	0.75	0.80	0.70	0.67	0.78	0.75	0.71	0.84	0.86
initial road type:									
dedicated lanes	1.00		1.00		1.00		1.00		0.60
rural motorways	0.63		0.73		0.71		0.76		0.88
urban motorways	1.00		0.80		1.00		0.7		1.00
rural roads	1.00		0.95		1.00		1.00		1.00
urban roads	0.50		0.93		1.00		1.00		1.00
initial user group:									
freight operators	0.54		0.17		0.17		0.40		0.62
commuters	0.91		1.00		0.93		1.00		1.00
leisure drivers	1.00		1.00		1.00		0.91		1.00
business drivers	0.62		0.94		0.82		0.84		1.00
elderly/disabled ¹	-		-		-		-		-
bus operators ¹	-		-		-		-		-

¹these groups have been proposed in the first round, hence no stability indices could be computed

Table A-2: Stability indices of opinions regarding barriers for AVG implementation (n=50)

system	SHK	FCAS	LKS	SCAS	AP
barriers					
policy goals:					
reduction of fatal accidents	0.93	0.81	0.70	0.77	0.90
reduction of accident severity	0.90	0.93	0.75	0.78	0.93
increase of road capacity	0.88	0.96	0.88	0.85	0.93
increase of driving convenience	0.81	0.96	0.81	0.96	0.92
reduction of environmental impacts	0.79	0.80	0.71	0.75	0.88
technical barriers:					
reliability: system doesn't support	0.90	1.00	1.00	0.90	0.91
accuracy: system support incorrect	1.00	0.91	0.93	0.92	0.93
danger of interference	0.92	0.92	0.89	0.96	0.93
parameter trade-off safety/effic./comf.	0.88	0.88	0.86	0.88	0.91
complexity decision- making algorit.	0.97	0.85	0.79	0.93	0.80
software safety verification ¹	-	-	-	-	-
technical durability ¹	-	-	-	-	-
driving barriers:					
counteracting driving behaviour	0.96	0.96	0.93	0.92	1.00
increase in driver workload	0.92	0.92	0.96	0.95	0.85
decrease in driver workload	0.93	0.89	0.89	0.92	0.93
danger of loosing driving skills	0.93	0.89	0.93	0.88	0.93
lack of driver education ¹	-	-	-	-	-
general barriers:					
purchase costs for the consumer	0.94	0.93	0.97	0.91	1.00
consumers perception system utility	0.78	0.88	0.96	0.9	0.96
public costs for road adaptations	0.84	0.82	0.87	0.8	0.95
liability allocation unclear	0.83	0.68	0.81	0.79	0.57
limited road network applicability	0.96	1.00	0.94	0.90	0.89
international system standardisation	0.88	0.90	0.86	0.86	0.88
consumer privacy ¹	-	-	-	-	-

¹these barriers have been proposed by the panel in first round, hence no stability indices could be computed

A.4 Concordance analysis of expert opinions

Concordance analyses has been applied to each set of barriers discussed in chapter 5. However, due to this approach, the difference between for instance highly important and important would affect the ranking of barriers as much as the difference between highly important and highly unimportant. To avoid this, the five point evaluation scoring scale used in the questionnaire has been transformed into a three point evaluation scoring scale. Using this scale, no distinction is made between respondents evaluating a barrier highly important or important, respectively highly unimportant or unimportant.

The resulting, standardised dominance scores and rankings are presented in Table A-3 to Table A-6. As in our study lower scores refer to more important (or more unlikely in Table A-3), the lowest dominance scores imply the most dominant barriers.

Table A-3: Ranking of likelihood of system contributions to general transport policy goals.

	system	supporting systems	autopilot
policy goals			
reduction of fatal accidents		0.17 ¹ [4] ²	-0.04 [3]
reduction of accident severity		0.22 [5]	-0.38 [1]
increase of road capacity		-0.25 [1]	0.02 [4]
increase of driving convenience		0.12 [3]	0.48 [5]
reduction of environmental impacts		-0.24 [2]	-0.08 [2]

¹ standardised dominance score; ² ranking position of barrier

Table A-4: Ranking of technical barriers for further developments.

	system	supporting systems	autopilot
technical barriers			
reliability: system doesn't support when expected		-0.22 ¹ [1] ²	-0.17 [1]
accuracy: system doesn't support in the right way		-0.21 [2]	-0.17 [1]
danger of interference with other in-car systems		0.25 [7]	0.42 [7]
parameter trade-off safety. efficiency. comfort		0.13 [6]	0.05 [6]
complexity decision making algorithms		0.07 [5]	-0.05 [4]
software safety verification		-0.07 [3]	-0.11 [3]
technical durability		0.05 [4]	0.03 [5]

¹ standardised dominance score; ² ranking position of barrier

Table A-5: Ranking of aspects of driving behaviour.

system	supporting systems	autopilot
driving barrier		
possible counteracting driving behaviour	-0.46 ¹ [1] ²	-0.25 [1]
possible increase in driver workload	0.30 [5]	0.46 [5]
possible decrease in driver workload	0.13 [4]	0.03 [4]
danger of losing driving skills	0.07 [3]	-0.18 [2]
lack of driver education	-0.04 [2]	-0.06 [3]

¹ standardised dominance score; ² ranking position of barrier

Table A-6: Ranking of general barriers for further developments.

system	supporting systems	autopilot
general barrier		
purchase costs for the consumer	-0.22 ¹ [1] ²	-0.19 [1]
consumers perception of system utility	-0.12 [3]	0.05 [5]
costs to public authorities for road adaptations	0.14 [6]	-0.06 [4]
liability allocation users. producers. road-owners unclear	-0.16 [2]	-0.15 [2]
limited road network applicability of system use	0.11 [5]	-0.09 [3]
international system standardisation difficult	0.07 [4]	0.09 [6]
consumers privacy	0.18 [7]	0.35 [7]

¹ standardised dominance score; ² ranking position of barrier

Appendix B.

The conjoint analysis survey

In this appendix the basic questionnaire is presented which has been used to elicit the preferences of consumers regarding early AVG concepts. As indicated in section 6.6, 6 variants of a basic questionnaire have been distributed for each of the six consumer groups. Next, the background questions differed to some degree for different consumer groups. All respondents were invited to indicate their basic social characteristics (gender, age and education). The vehicle driver respondents were further questioned on the number of years they owned their license, their type of vehicle ownership, the price of their vehicle, and their vehicle use. Fleet-operator respondents were questioned on their fleet size, the prices of vehicles within their fleet and the amount of kilometres driven by their fleet. Finally, the familiarity of the respondents with the systems questioned was elicited. Summarising, in total 36 similar questionnaires have been distributed. In this section, an example of one questionnaire as sent to vehicle drivers is presented.

The accompanying letter

Dear driver/fleet-operator,

At this moment we are conducting a study regarding the implementation of new in-vehicle systems which intend to make vehicle driving more safe and more comfortable. Manufacturers of cars, trucks and buses are currently developing systems which support drivers in avoiding collisions with other vehicles. Furthermore, systems are developed which support drivers in keeping their lane and to avoid road departures

To what extent these systems really improve the traffic safety is still uncertain. This is strongly depending upon how drivers use these systems and the number of vehicles which is equipped with these systems. Some of these systems might contribute to a less travel time and a reduction of fuel consumption, whereas other systems might negatively influence these issues. Therefore, in the attached questionnaire, we ask for your opinion regarding these systems. This will be used to give recommendations to the Dutch government in order to stimulate the implementation of systems which improve the driving performance and to discourage the implementation of systems which does not.

This study is part of independent, scientific research within Delft University of Technology. Your answers will be handled confidential and anonymous. The success of this study depends on your cooperation. We understand that your time is precious and, therefore, we have tried to keep the questionnaire as short as possible. If desired, you can get a summary of the results of the survey.

We invite you to fill in the attached questionnaire and return it within two weeks. If you have questions or remarks you can contact Vincent Marchau. Thanks in advance for your cooperation,

Ir. Vincent Marchau,
Prof. Rob van der Heijden.

Instructions for the questionnaire

In the attached questionnaire, eighteen different systems are presented which can be placed in vehicles. You are invited to judge these systems. Below, you will find an explanation of the systems and instructions how to give your opinion. Please, do read these well before starting with the questionnaire.

The systems concerned in this survey, can support drivers with regard to distance keeping, lane keeping and lane changing. For that, these systems electronically guard the distance preceding vehicles, the vehicle position on the road and the vehicles in adjacent lanes. In case of collision danger or potential roadway departure, these systems can support the driver in different ways. Some systems only warn the driver while other systems assist the driver actively by automatic control of brakes, throttle and steer.

Each system can be turned on or off by the driver. The systems function under all weather conditions including darkness, fog, slipperiness, etc. The systems are designed for use on motorways.

Each system can be described on the basis of the following six characteristics. We distinguish technical characteristics (functions) and non-technical characteristics (cost-benefits)

Function 1: distance keeping

Each system guards the distance of the vehicle to the preceding vehicle. In case the following distance falls below a certain level, these systems can initiate one of the following actions:

- distance warning: the system warns the driver that the following distance is too low;
- throttle assistance: this system follows the preceding vehicle by automatically throttle control. The driver need to intervene in case of emergency stops. In case of no preceding vehicle the system functions as cruise control;
- throttle & brake control: the system follows the preceding vehicle by automatically throttle control. The system also takes care of emergency braking. In case of no preceding vehicle the system functions as cruise control.

Function 2: lane keeping

Some system guards the vehicle position with regard to the road geometry. In case of potential roadway/lane departure (turn indicator off) the system can:

- give no lane keeping support: this system does not support the drivers lane keeping;
- initiate a warning: the driver is warned that for impending roadway/lane departure;
- initiate steering assistance: the system follows the road/lane marks by automated steering control.

Function 3: lane changing

This function guards the speed and position of the vehicle(s) in adjacent lanes. In case the driver intends to change lanes (turn indicator on), e.g. for overtaking or for merging, the system can:

- give no lane keeping support: this system does not support the drivers lane changing;
- initiate a warning: the driver is warned that for impending collisions with the vehicle(s) in adjacent lanes;
- initiate steering assistance: the system avoids a collision with the vehicle(s) in adjacent lanes by initiating automated steering control.

Cost/Benefits 1: price

The system costs refer to the purchase price of the system to the consumer. The operating costs can be ignored. The price of a system is defined in the write-off of the system-price per year, assuming that a system is written off within a time period of five years. Different systems can give the following differences in these costs per year (\$ = US dollar):

- \$100;
- \$300;
- \$500;

Cost/Benefits 2: travel time performance

Some systems decrease the travel time, on average, as they induce an improved use of the road capacity (closer following to preceding vehicles) and/or lower the risk regarding collisions. Other systems might increase the travel time as they, for instance, induce large headways. Different systems can change the travel time in different ways:

- 10% more travel time;
- an equal travel time;
- 10% less travel time.

Cost/Benefits 3: fuel performance

Some systems support the driver in driving more smoothly (less speed variation in both longitudinal and lateral direction) This improves the vehicle's fuel performance. Other systems increase the vehicle's fuel performance. Different systems can change the fuel performance of a vehicle in different ways:

- 5% more fuel consumption;
- an equal fuel consumption;
- 5% less fuel consumption.

Each system is presented in terms of these characteristics. Consider for instance the system below. The system needs to be evaluated in the following way:

- consider first only the technical functions of the system;
- answer question 1 and 2: please indicate a score on the presented response scale from '-2' to '+2', according to your opinion;
- next, consider also the cost-benefit characteristics of the system
- answer question 3, this question refers to both the technical functions and the cost cost-benefit characteristics of the system: please indicate a score on the presented response scale from '0' to '10'.

system profile

technical functions:

distance warning

no lane keeping support

no lane change support

cost/benefits:

price = \$500

10% more travel time

5% more fuel consumption

- a. To what degree will these technical functions change your driving comfort?
much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
extremely unattractive 0 1 2 3 4 5 6 7 8 9 10 extremely attractive

Questionnaire

Below you will find eleven system profiles. Please, for each profile, fill in the questions a, b and c according to the instructions given above:

system profile 1*technical functions:*

distance warning
no lane keep support
no lane change support

costs/benefits:

\$100 per year
+10% travel time
+5% fuel consumption

- a. To what degree will these technical functions change your driving comfort?
much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
extremely 0 1 2 3 4 5 6 7 8 9 10 extremely
unattractive attractive

system profile 2*technical functions:*

throttle & brake assist
lane keep steer assist
lane change steer assist

costs/benefits:

\$500 per year
-10% travel time
-5% fuel consumption

- a. To what degree will these technical functions change your driving comfort?
much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
extremely 0 1 2 3 4 5 6 7 8 9 10 extremely
unattractive attractive

system profile 3

technical functions:

- distance warning
- lane keep warning
- lane change warning

costs/benefits:

- \$500 per year
- equal travel time
- equal fuel consumption

- a. To what degree will these technical functions change your driving comfort?
much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
extremely unattractive 0 1 2 3 4 5 6 7 8 9 10 extremely attractive

system profile 4

technical functions:

- distance warning
- lane keep steer assist
- lane change steer assist

costs/benefits:

- \$300 per year
- 10% travel time
- 5% fuel consumption

- a. To what degree will these technical functions change your driving comfort?
much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
extremely unattractive 0 1 2 3 4 5 6 7 8 9 10 extremely attractive

system profile 5

technical functions:

throttle assist
 no lane keep support
 lane change warning

costs/benefits:

\$300 per year
 equal travel time
 -5% fuel consumption

- a. To what degree will these technical functions change your driving comfort?
 much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
 much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
 extremely 0 1 2 3 4 5 6 7 8 9 10 extremely
 unattractive attractive

system profile 6

technical functions:

throttle assist
 lane keep warning
 lane change steer assist

costs/benefits:

\$100 per year
 -10% travel time
 +5% fuel consumption

- a. To what degree will these technical functions change your driving comfort?
 much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
 much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
 extremely 0 1 2 3 4 5 6 7 8 9 10 extremely
 unattractive attractive

system profile 7*technical functions:*

throttle assist

lane keep steer assist

no lane change support

costs/benefits:

\$500 per year

+10% travel time

equal fuel consumption

- a. To what degree will these technical functions change your driving comfort?
much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
extremely unattractive 0 1 2 3 4 5 6 7 8 9 10 extremely attractive

system profile 8*technical functions:*

throttle & brake assist

no lane keep support

lane change steer assist

costs/benefits:

\$500 per year

equal travel time

+5% fuel consumption

- a. To what degree will these technical functions change your driving comfort?
much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
extremely unattractive 0 1 2 3 4 5 6 7 8 9 10 extremely attractive

system profile 9

technical functions:

throttle & brake assist
 lane keep warning
 no lane change support

costs/benefits:

\$300 per year
 -10% travel time
 equal fuel consumption

- a. To what degree will these technical functions change your driving comfort?
 much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
 much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
 extremely 0 1 2 3 4 5 6 7 8 9 10 extremely
 unattractive attractive

system profile 10

technical functions:

throttle & brake assist
 lane keep steer assist
 lane change warning

costs/benefits:

\$100 per year
 +10% travel time
 -5% fuel consumption

- a. To what degree will these technical functions change your driving comfort?
 much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
 much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
 extremely 0 1 2 3 4 5 6 7 8 9 10 extremely
 unattractive attractive

system profile 11

technical functions:

throttle assist

lane keep warning

lane change warning

costs/benefits:

\$300 per year

equal travel time

equal fuel consumption

- a. To what degree will these technical functions change your driving comfort?
much more uncomfortable -2 -1 0 1 2 much more comfortable
- b. To what degree do will these technical functions change your driving safety?
much unsafer -2 -1 0 1 2 much safer
- c. How attractive would you find it to have this total system in your vehicle?
extremely unattractive 0 1 2 3 4 5 6 7 8 9 10 extremely attractive

Personal questions:

Question 1. What is your gender?

- Male
- Female

Question 2. What is your year of birth? 19.....

Question 3. Indicate your highest level of education:

- less than secondary school
- bachelor or higher
- other:

Question 4. Which of the following types of car-ownership applies to you?

- private car – less than 50% of the car kilometres driven is for business purposes
- private car – more than 50% of the car kilometres driven is for business purposes
- company car – your employer pays all your car expenses
- other:

Question 5. How many years do you have your driving license?

.....years

Question 6. What is the recommended retail price of your vehicle?

.....,

Question 7. About how many kilometres do you drive on motorways per week (including the weekend)?
.....km

Question 8. Please indicate if your car is currently equipped with one of the following, electronic systems:

speed adapter:	1. yes	2. no
cruise control:	1. yes	2. no
navigation system:	1. yes	2. no
back up control:	1. yes	2. no
anti lock braking system/ traction control:	1. yes	2. no
other systems:	.....

Question 9. Are you familiar with the systems presented in the questionnaire?

- not familiar
- moderate familiar
- quite familiar

In case you have any further remarks, please give these below:

.....
.....
.....

Summary

Introduction

Large technological progress has been made in the field of Automated Vehicle Guidance (AVG). The automation of the driver's throttling, braking, and steering tasks is expected to make vehicle driving safer and more convenient. Together with substantial reductions in travel time due to better traffic throughput, fuel consumption, and emissions, this implies high potential individual and societal advantages.

In various countries, therefore, transport policy makers are increasingly interested in the automation of vehicle driving tasks. However, current policy development regarding AVG is highly complicated by much uncertainty on future AVG development and implementation in terms of: the likely development of AVG technology implementation, whether this development will contribute to or conflict with transport policy goals, and the basic societal conditions required for AVG implementation.

Research is strongly focused on the technical possibilities of AVG. The more societal-oriented questions to be answered and choices to be made are still hardly considered. This could hinder AVG developments in an early stage or lead to the implementation of AVG systems which serve producers and individual consumers' interests only, and not more general transport policies. In terms of research this implies that the efforts on AVG technology development should be balanced with research on the non-technological dimensions of AVG implementation.

Research objective and approach

The field of interdisciplinary research on the possibilities and consequences of technology implementation in general is referred to as Technology Assessment (TA). However, the field of TA is broad and does not offer a clear body of scientific knowledge for clearly specifying a methodology to tackle the research problem within this thesis. The main objective within this thesis therefore is:

the specification, operationalisation, and application of an innovative TA approach to identify and reduce the uncertainty of future AVG implementation.

In order to realise the research objective, the study focuses on the following questions:

1. *What methodological approach can be based upon the field of TA to cope with the uncertainties regarding future AVG implementation?*
2. *(a) How can the long-term uncertainties be better structured in order to allow for more in-depth analysis of plausible developments for the medium term (up to 2020/2025)? (b) What are the results of this analysis?*
3. *(a) How can conditions of plausible technology applications for this time period be analysed in-depth? (b) What are the results of this analysis?*
4. *(a) How can the likeliness of these developments be explored, from the perspective of crucial stakeholders, for a successful, near-term implementation? (b) What are the results of this analysis?*
5. *What conclusions can be drawn with regard to the role of public authorities in relation to AVG development?*

The results should provide knowledge on the societal conditions for the implementation of AVG technology to the public authorities involved, in order to support the development of their policy strategy and to identify important issues for follow-up, in-depth research.

A conceptual approach for Technology Assessment AVG

In order to specify a methodology for coping with uncertainty of future AVG implementation, the field of Technology Assessment (TA) has been explored. In particular the field of TA has been structured by distinguishing different TA styles (Awareness TA, Strategic TA, and Constructive TA) and different TA approaches (analytical, intervening and reflecting). In this thesis only the analytical TA approaches are of interest, as the aim of our research involves an analysis of the technology development.

It is argued that the choice of a TA style and of a specific analytical TA research approach cannot be made without first having structured and limited the issue of AVG implementation. A systematic view regarding AVG implementation points out that a TA style is needed which links contingency information on AVG technology development with

information related to future decision making of stakeholders. Therefore, a Strategic TA (STA) style seems appropriate. Methodologically, a backcasting approach is argued which limits the scope of policy development and research by eliminating parts of the large variety in possible AVG developments. This approach implies the following steps: (1) the specification of plausible AVG concepts; (2) the analysis of the conditions for the implementation of these concepts, and (3) the analysis whether stakeholders' decisions and actions related to the conditions for the implementation of plausible concepts will be fulfilled in time. The result of this approach is the elimination of non-plausible and non-accepted AVG concepts and the reduction of the scope within policy making to the most promising concepts.

The specification of plausible AVG concepts

The first step involves the specification of plausible AVG concepts. The main purpose in this step is structuring and limiting the set of plausible AVG concepts from the public policy making point of view. Morphological analysis is applied in this step. In general, morphological analysis converts a system concept under study in terms of basic dimensions and possible values along these dimensions. Next, a multi-dimensional solution space is constructed by considering all combinations of values. These combinations are evaluated in order to select the most promising alternatives.

The analysis points out that it is possible to limit the set of future possible AVG concepts to manageable proportions, which enables further, in-depth research. Several AVG concepts were found logically implausible. By further application of a temporal dimension, seven groups of plausible, evolving AVG concepts can be defined. Basically, the future implementation of these concepts depends upon the assumption one has on the nature of future AVG developments. Assuming that the implementation of these concepts will basically follow an evolutionary pattern implies that it is most likely that first there will be informing and assisting intelligence in vehicles, either for longitudinal or lateral support, functioning in a mixed situation with conventional vehicles and applicable on motorways only. In case a more revolutionary development is assumed, the development could start with the implementation of fully automated devices in vehicles and infrastructure, for both longitudinal and lateral support, functioning on dedicated lanes for target groups only.

Evaluating plausible AVG concepts

The next step involves a more in-depth analysis of the selected set of plausible AVG concepts, in relation to the basic conditions postulated for each of the concepts. This implies identifying and evaluating the initial market characteristics of the different AVG concepts and the barriers which might obstruct market introduction and/or further deployment. The expertise and insights of experts are considered appropriate for this type of analysis, as empirical data is lacking and extrapolation from past observations would be an invalid approach.

An international Delphi study among experts points out that an evolutionary development of AVG is not as obvious as often assumed. There still exist many barriers which obstruct successful implementation. Only in the short term, i.e. before 2005, there exists strong consensus that warning devices for speed headway keeping, lane keeping and obstacle avoidance will become (further) available, next to vehicle-following systems with limited deceleration capabilities. Next, systems which assist the driver in preventing collisions with moving or stationary front vehicles are likely to become available between 2005 and 2010. This also yields lane keeping control systems. The introduction of more advanced systems taking temporary control of the vehicle in case of dangerous situations is still considered uncertain. Electronic control devices for side obstacle collision avoidance are not expected to become available before 2010. In general, the market entrance and penetration of supportive systems will, next to consumer acceptance, largely depend on future technological progress of systems' operating capabilities and transparency concerning liability issues. Overall, supportive systems are all expected initially to be of use within motorway environments only and to be adopted by professional drivers and fleet-operators. The contribution of most of these support systems to road capacity gains and reduction of environmental impacts is (highly) uncertain. Moreover, safety improvements may be achieved but these are strictly limited to those driving situations the system is designed for and these could easily be countermeasured by more risky driving behaviour. Most uncertain seems the implementation of the autopilot, due to various technical as well as non-technical arguments.

As the implementation of more advanced AVG systems appears (highly) uncertain, a stronger focus on systems implementable in the short term is required. In terms of research, it requires the identification of the parties being involved as well as the willingness and possibility of those parties to act.

Consumers preferences regarding early AVG implementation

The next step is to gain more insight into the preferences consumers have when being confronted with these systems. We are, in particular, interested in the relationship between the features of systems and the preferences of consumers.

An approach is adopted which is frequently applied in other fields of research and which is known as a decompositional stated preference approach, also referred to as conjoint analysis. Conjoint analysis makes use of hypothetical profiles which integrally describe AVG concepts and to which respondents are requested to provide overall evaluations. According to this view, individuals are assumed to evaluate alternative AVG concepts as bundles of attributes and the preference for a particular alternative is based on combining part-worth utilities of separate attributes.

Both drivers and fleet-operators of cars, trucks and buses have been questioned about their preferences regarding several alternatives of early AVG concepts. Alternatives were presented based on their functional features, different levels of system price and varying impacts on travel time and fuel consumption. On average, drivers and fleet-operators judge

it somewhat unattractive to have early AVG systems in their vehicle(s) somewhat unattractive. However, the study shows that this finding needs to be nuanced as the stated preferences depend on the specific system characteristics.

Overall, technical functions of systems are evaluated less important than the costs and benefits of the system. The price of a system influences the attractiveness most. Next, systems which negatively influence travel time performance or fuel consumption, lower the overall utility rapidly. This indicates that one should take care of implementing early AVG systems that influence travel time and fuel consumption negatively. Warning support on distance keeping is preferred to throttle control and throttle- and brake control. For lane keeping and changing warning devices are even preferred to no support or steering assistance. Considering different markets the attractiveness of systems is evaluated equally by both drivers and fleet-operators. It was further found that truck drivers and car fleet-operators consider AVG systems more attractive as compared to the other driver groups respectively the other fleet-operator groups. Hence, these groups can be considered initial target groups for implementation. Within the category of car drivers, business drivers evaluate the systems more attractive than private drivers. So, in addition to truck drivers and car fleet-operators, business drivers might be considered an interesting market for initial implementation as well. Hence, the business-car market is promising in terms of recommendations for implementation strategies. As for the truck market, truck operators consider AVG systems moderately unattractive and might, as such, be reluctant to the implementation of early AVG systems.

Conclusions and implications

In this thesis the challenge has been to develop and apply an innovative TA approach to identify and reduce the large uncertainty on future AVG development and implementation.

The conceptual TA approach developed within this thesis can be considered complementary to traditional TA exercises undertaken in the field of AVG which usually study different aspects of AVG systems in-depth. It is recommended that, in case of large uncertainty with regard to both the technological progress and the organisational process of technology implementation, one should perform a TA study using both approaches, as both separate approaches have their limitations. In this way a maximum insight into all relevant aspects of technology implementation can be obtained. With regard to the approach in this study a problem is the lack of scientific knowledge to specify, operationalise and apply a TA approach. Therefore, comparative assessments using different methodological approaches are recommended. This should provide TA researchers with scientific criteria for setting up a TA study and choosing particular methods.

The application of the conceptual approach has resulted in the identification and reduction of uncertainty regarding the future implementation of AVG. The theoretical assumption that the implementation of AVG concepts is likely to take place in an evolutionary way, has only partly been confirmed. There are still several barriers to be dealt with before such an evolution, if ever, will become reality. It appears that only the (further)

introduction of various warning devices for driving support as well as vehicle-following systems with limited deceleration capabilities is most certain in the short-term. More advanced systems, although expected to be introduced in the medium term, are uncertain to evolve further on. The implementation of further automation in the next few decades, up to the level of the autopilot, appeared highly uncertain.

In the short term, AVG implementation is expected to be dominated by market opportunities in terms of the behaviour of potential consumers. On average, these consumers ('motorway' drivers and fleet-operators) evaluate early AVG systems to be somewhat unattractive to have in their vehicle(s). However, the attractiveness of AVG systems depends strongly on the system operating characteristics as well as on the specific consumer group. As expected, higher system prices show a decrease in attractiveness and systems which influence the travel time and the fuel consumption negatively are strongly disfavoured to systems which do not. Warning devices are preferred to systems taking temporary control. Furthermore, there is a need for lateral (warning) support among consumers. When considering different consumer groups, truck drivers, car fleet-operators and business drivers might be considered interesting initial markets.

Given the findings of the research performed within this thesis, we are now able to recommend some future policy actions in order to guide further developments of AVG into a societal desired way. A continuation of further management of AVG research and development is considered important. However, this effort should shift from supporting the technical design and testing sophisticated prototypes towards specifying the functionality for AVG concepts from a societal point of view.

The contribution of support systems to general transport policy goals has been found unlikely or might even be negative for the coming two decades. Public authorities have the responsibility to specify performance indicators and values these systems should meet in order to avoid negative impacts on overall traffic flow efficiency and safety. This would give more direction to the technical focus of these systems.

Also today's legislation on liability needs attention to be able to deal with the possible consequences of more intervening systems, for instance front and side obstacle avoidance systems. The current lack of transparency in legal regulations should be solved, as this leads to hesitating stakeholders and, due to this delay, the development and implementation of systems developed with high R&D costs.

Next, public authorities should consider to become more involved as AVG implementator in the future. Inter-vehicle and vehicle-road communication might improve system performance and accelerate the introduction of more advanced systems.

Finally, the acceptance of potential users of AVG should be improved. Various strategies contribute to this goal such as demonstrations, pilots, and strategic niche management (for e.g. professional road users). The adoption of AVG technologies by consumers likely requires stimulating measures according to specific needs and preferences. Next to financial incentives, one could think of stimulating the implementation of systems which do not affect fuel consumption and travel time in a negative way, as well as supporting drivers by warning devices instead of controlling devices, etc.

Summarising, a more active public policy making in the context of AVG implementation can and should be undertaken in a number of ways. We hope that our research will support the development of the current and future policy strategy of public bodies.



Samenvatting

Introductie

In de afgelopen jaren worden de ontwikkelingen rondom Automatische Voertuig Geleiding (AVG) gekenmerkt door een grote technologische vooruitgang. De verwachting is dat de automatisering van rijtaken (gas geven, remmen en sturen) de verkeersveiligheid en het rijcomfort zal verhogen. Daarnaast kan AVG bijdragen aan kortere reistijden (als gevolg van een verbeterde doorstroming), verlaging van het brandstofverbruik en de uitstoot van schadelijke emissies. Als zodanig biedt AVG, in potentie, hoge individuele en maatschappelijke voordelen.

Transport beleidsmakers uit allerlei landen zijn daarom in toenemende mate geïnteresseerd in de automatisering van rijtaken. Echter de beleidsontwikkeling rondom AVG is zeer gecompliceerd als gevolg van grote onzekerheid over de toekomstige AVG ontwikkeling en implementatie in termen van: de waarschijnlijke ontwikkeling van AVG technologie implementatie, of deze ontwikkeling wel of niet zal bijdragen aan algemene transport beleidsdoelen, en de maatschappelijke condities die nodig zijn voor de implementatie van AVG.

Het onderzoek is voornamelijk gericht op technologische mogelijkheden van AVG. De meer maatschappelijke vraagstukken en keuzes inzake AVG worden niet of nauwelijks beschouwd. Dit zou de AVG ontwikkeling kunnen stoppen in een vroeg stadium of zou ertoe kunnen leiden dat slechts die AVG systemen geïmplementeerd worden die alleen de belangen van producenten en consumenten dienen en niet meer algemene transportdoelen. In termen van onderzoek betekent dit dat de inspanning rondom AVG technologie ontwikkeling in samenhang beschouwd zou moeten worden met de niet-technologische dimensies van implementatie van AVG.

Onderzoeksdoel en benadering

Het interdisciplinaire vakgebied wat zich bezighoudt met de mogelijkheden en gevolgen van technologie-ontwikkeling en implementatie in het algemeen staat bekend als Technology Assessment (TA). Echter, het TA vakgebied is breed en biedt geen helder wetenschappelijk kader voor de directe specificatie van een methodologie om het onderzoeksprobleem in dit proefschrift te behandelen. Daarom is het centrale onderzoeksdoel in dit proefschrift:

de specificatie, operationalisatie en toepassing van een innovatieve TA benadering teneinde de onzekerheid van toekomstige AVG implementatie te identificeren en te reduceren.

Om dit doel te bereiken zal de studie zich richten op de volgende vragen:

1. *Welke methodologische benadering kan afgeleid worden vanuit het TA vakgebied om met de onzekerheden om te gaan inzake de toekomstige implementatie van AVG?*
2. *(a) Hoe kunnen lange termijn onzekerheden gestructureerd te worden om een nadere analyse van plausibele ontwikkelingen voor de middellange termijn mogelijk te maken (tot 2020/2025)? (b) Wat zijn de resultaten van deze analyse?*
3. *(a) Hoe kunnen condities van plausibele technologie-applicaties voor deze termijn nader geanalyseerd worden? (b) Wat zijn de resultaten van deze analyse?*
4. *(a) Hoe kan de waarschijnlijkheid van deze ontwikkelingen verkend worden voor succesvolle implementatie op de korte termijn, vanuit het perspectief van cruciale betrokkenen? (b) Wat zijn de resultaten van deze analyse?*
5. *Welke conclusies kunnen getrokken worden voor de rol van overheden inzake AVG ontwikkeling?*

Dit onderzoek beoogt kennis te genereren inzake de maatschappelijke condities van de implementatie van AVG technologie, teneinde strategievorming van beleidsmakers te ondersteunen en belangrijke onderwerpen voor vervolgonderzoek te identificeren.

Een conceptuele benadering voor Technology Assessment AVG

Het vakgebied Technology Assessment (TA) is verkend om een methodologie te specificeren voor het omgaan met de onzekerheid van toekomstige AVG implementatie. In het bijzonder is het vakgebied TA nader gestructureerd door verschillende TA stijlen (Reactieve of 'Awareness' TA, Strategische TA, and Constructieve TA) en verschillende TA benaderingen (analytisch, interveniërend en reflectief) te onderscheiden. In dit proefschrift zijn alleen de analytische TA benaderingen van belang, daar het doel van ons onderzoek de analyse van technologie-ontwikkelingen betreft.

Het blijkt dat de keuze voor een TA stijl en een specifieke analytische TA benadering alleen gemaakt kan worden indien het subject van onderzoek, AVG implementatie, nader gestructureerd en afgebakend wordt. Een systeemvisie op de implementatie van AVG wijst uit dat er een TA stijl nodig is die inhoudelijke informatie van AVG technologie-ontwikkeling relateert aan het toekomstig beslisgedrag van betrokken partijen. Een Strategische TA (STA) stijl lijkt de juiste in dit opzicht. Methodologisch wordt een 'backcasting' benadering voorgesteld die de variëteit aan mogelijke, toekomstige AVG ontwikkelingen voor beleid en onderzoek limiteert door onderdelen van deze variëteit te elimineren. Deze benadering bestaat uit de volgende stappen: (1) de specificatie van plausibele AVG concepten; (2) de analyse van de condities voor de implementatie van deze concepten, en (3) de analyse of de beslissingen en acties van betrokken partijen voor de implementatie van deze concepten op tijd uitgevoerd zullen worden. Het resultaat van deze benadering is de eliminatie van niet-plausibele and onacceptabele AVG concepten en een reductie van de variëteit aan toekomstig mogelijke AVG concepten tot de meest veelbelovende AVG concepten.

De specificatie van plausibele AVG concepten

De eerste stap betreft het specificeren van plausibele AVG concepten. Het gaat hier in het bijzonder om het structureren en limiteren van de verzameling van plausibele AVG concepten vanuit het perspectief van publieke beleidsontwikkeling. Om deze stap uit te kunnen voeren, is morfologische analyse toegepast. Morfologische analyse behelst de vertaling van een systeemconcept in termen van basisdimensies en mogelijke waarden die deze dimensies kunnen aannemen. Vervolgens wordt een meer-dimensionale oplossingsruimte geconstrueerd door alle mogelijk combinaties van waarden te beschouwen. Deze combinaties worden dan geëvalueerd teneinde de meest veelbelovende alternatieven te selecteren.

Het blijkt dat de verzameling van toekomstig mogelijke alternatieve AVG concepten te limiteren is tot hanteerbare proporties die nader, diepgaand onderzoek mogelijk maken. Een groot aantal AVG concepten blijkt logischerwijs niet plausibel. De verdere toepassing van een temporele dimensie resulteert in de identificatie van zeven groepen van plausibele, evoluerende AVG concepten. De toekomstige implementatie van deze concepten hangt af van de assumptie die men heeft inzake het karakter van toekomstige AVG ontwikkelingen. Indien aangenomen wordt dat de implementatie van AVG concepten grotendeels gekenmerkt zal worden door een evolutionair patroon, impliceert dat er zeer waarschijnlijk eerst informerende en assisterende intelligentie in voertuigen geïmplementeerd zal worden, ter ondersteuning van longitudinale of laterale rijtaken, functionerend in gemengd verkeer met niet-uitgeruste voertuigen en alleen te gebruiken op snelwegen. Indien een meer revolutionaire ontwikkeling wordt verondersteld, zou de ontwikkeling kunnen starten met de implementatie van volledig automatische intelligentie, deels in voertuigen en deels in de weg, zowel voor longitudinale als voor laterale rijtaken, alleen functionerend op aparte rijstroken voor bepaalde doelgroepen.

Een evaluatie van plausibele AVG concepten

De volgende stap betreft een meer diepgaande analyse van de geselecteerde verzameling van plausibele AVG concepten, in termen van de condities gepostuleerd voor ieder concept. Dit impliceert de identificatie en evaluatie van initiële marktkenmerken van de verschillende AVG concepten en de factoren die marktintroducties en/of verdere ontwikkelingen belemmeren. De expertise en inzichten van experts worden hierbij geschikt geacht, daar empirische gegevens ontbreken in deze context en het extrapoleren van observaties uit het verleden onjuist zou zijn.

Een internationale Delphi studie onder experts wijst uit dat een evolutionaire ontwikkeling van AVG niet zo evident is als vaak wordt verondersteld. Er zijn nog steeds obstakels voor een succesvolle implementatie van AVG. Alleen voor de korte termijn (tot 2005) bestaat er sterke overeenstemming onder de experts dat waarschuwendende systemen voor de ondersteuning van afstand houden, koers houden en het vermijden van obstakels (verder) beschikbaar zullen komen, naast voertuigvolg-systemen met beperkte deceleratiemogelijkheden. Tussen 2005 en 2010 zullen waarschijnlijk systemen beschikbaar komen die de bestuurders rijtaak tijdelijk overnemen ter voorkoming van ongevallen met bewegende of stilstaande voertuigen alsmede met betrekking tot het volgen van een juiste koers. De introductie van geavanceerdere systemen die tijdelijk de rijtaak overnemen in geval van gevaarlijke situaties is vooralsnog onzeker. Het wordt niet verwacht dat elektronische botsingsvermijding-systemen voor laterale obstakels voor 2010 beschikbaar zullen komen. De marktintroductie van ondersteunende systemen in het algemeen zal afhangen van de acceptatie van consumenten, de technologische vooruitgang van de operationele mogelijkheden van systemen en de transparantie inzake wettelijke aansprakelijkheid. Verder wordt verwacht dat ondersteunende systemen initieel alleen voor gebruik op snelwegen geschikt zullen zijn en door professionele weggebruikers en vlootbeheerders geadopteerd zullen worden. De bijdragen van de meeste ondersteunende systemen aan een verhoging van de wegcapaciteit en een reductie van de milieubelasting zijn (zeer) onzeker. De invloed van ondersteunende systemen op de verkeersveiligheid zou mogelijk wel positief kunnen zijn, maar deze is sterk beperkt tot alleen die verkeerssituaties waarvoor systemen ontworpen zijn. Daarnaast kunnen behaalde veiligheidsvoordelen tenietgedaan worden door risicovoller rijgedrag. Het meest onzeker blijkt de implementatie van de automatische piloot in voertuigen, als gevolg van allerlei technische en niet-technische argumenten.

Daar de implementatie van meer geavanceerde AVG systemen (zeer) onzeker lijkt, is er meer aandacht nodig voor systemen die implementeerbaar zijn in de nabije toekomst. In termen van onderzoek impliceert dit de identificatie van de betrokken partijen en hun mogelijkheid en bereidwilligheid om te handelen.

De voorkeuren van consumenten inzake de implementatie van de eerste AVG systemen

De volgende stap is het verkrijgen van meer inzicht in de voorkeuren van potentiële consumenten inzake AVG systemen. In het bijzonder zijn we geïnteresseerd in de relatie tussen systeem-kenmerken en deze voorkeuren.

Een benadering die vaak wordt toegepast binnen andere onderzoeksgebieden, beter bekend als de decompositionele stated preference benadering of conjuncte analyse, wordt hiervoor gebruikt. Conjuncte analyse maakt gebruik van hypothetische profielen die de AVG concepten integraal beschrijft en waarvoor respondenten worden uitgenodigd om een algemeen oordeel te geven. Deze aanpak veronderstelt dat individuen alternatieve AVG concepten evalueren in termen van bundels van attributen of kenmerken en dat de voorkeur voor een bepaald alternatief gebaseerd is op een combinatie van deelen van afzonderlijke attributen.

Zowel bestuurders als vlootbeheerders van auto's, vrachtwagens en bussen zijn ondervraagd over hun voorkeuren betreffende allerlei alternatieve AVG concepten voor de nabije toekomst. De alternatieven werden gepresenteerd in termen van hun functionele eigenschappen, verschillende prijsniveaus en verschillende effecten op reistijd en brandstofverbruik. In het algemeen beoordelen chauffeurs en vlootbeheerders het enigszins onaantrekkelijk om de eerste AVG systemen in hun voertuig(en) te hebben. Het blijkt echter dat deze bevinding genuanceerd dient te worden, daar de voorkeuren sterk fluctueren met de specifieke systeem-kenmerken.

In het algemeen worden de technische functionaliteiten van de systemen minder belangrijk beoordeeld dan de kosten en de baten van systemen. De prijs van een systeem beïnvloedt de aantrekkelijkheid het meest. Daarnaast verlagen systemen die de reistijd en het brandstofverbruik negatief beïnvloeden snel het algehele nut. Dit impliceert dat men voorzichtig moet zijn met de implementatie van AVG systemen die de reistijd en het brandstofverbruik negatief beïnvloeden. Waarschuwend ondersteuning voor afstand houden wordt geprefereerd boven tijdelijke overname van gaspedaal en gas- en rempedaal. Met betrekking tot ondersteuning van koers houden en inhalen worden waarschuwend systemen zelfs geprefereerd boven geen ondersteuning of tijdelijke overname van de stuurtaak.

In het algemeen beoordelen bestuurders en vlootbeheerders de systemen hetzelfde. Echter, vrachtwagenchauffeurs en wagenparkbeheerders vinden de AVG systemen aantrekkelijker in vergelijking tot andere chauffeurs (auto's, bussen) respectievelijk vlootbeheerders (vrachtwagens, bussen). Als zodanig kunnen deze groepen als eerste doelgroepen beschouwd worden. In de categorie autobestuurders evalueren de zakelijke rijders de systemen aantrekkelijker dan de niet-zakelijke rijders. Dus naast vrachtwagenchauffeurs en wagenparkbeheerders kunnen zakelijke rijders als een interessante markt beschouwd worden voor de implementatie van de eerste AVG systemen. In het bijzonder blijkt de markt van zakelijke auto's veelbelovend voor implementatie en minder voor de vrachtwagenmarkt, daar de vlootbeheerders van vrachtwagens de AVG

systemen enigszins onaantrekkelijk beschouwen en als zodanig terughoudend zouden kunnen zijn t.o.v. de implementatie van de eerste AVG systemen.

Conclusies en aanbevelingen

De uitdaging in dit proefschrift bestond uit de ontwikkeling en toepassing van een innovatieve TA benadering om de grote mate van onzekerheid van toekomstige AVG ontwikkelingen en implementatie te identificeren en te reduceren.

De in dit proefschrift ontwikkelde, conceptuele TA benadering kan complementair beschouwd worden aan de meer traditionele TA studies die uitgevoerd zijn betreffende AVG. In deze studies worden meestal verschillende aspecten van AVG systemen diepgaand onderzocht. Indien er sprake is van grote onzekerheid met betrekking tot technologische vooruitgang en het organisatorische proces van technologie implementatie, wordt het aanbevolen om een TA studie uit voeren waarin beide benaderingen toegepast worden, daar de afzonderlijke benaderingen hun beperkingen hebben. Op deze wijze wordt maximaal inzicht verkregen in alle relevante aspecten van technologie implementatie. De benadering in deze studie heeft het probleem dat wetenschappelijke kennis ontbreekt om een TA benadering te specificeren, operationaliseren en toe te passen. Daarom wordt aanbevolen om vergelijkende studies uit te voeren met verschillende methodologische benaderingen. Dit zou TA onderzoekers moeten voorzien van wetenschappelijke criteria voor het opzetten van een TA studie en het kiezen van specifieke methoden.

De toepassing van de conceptuele benadering heeft geresulteerd in de identificatie en reductie van onzekerheid inzake de toekomstige implementatie van AVG. De theoretische veronderstelling dat de implementatie van AVG concepten waarschijnlijk zal plaatsvinden volgens een evolutionair patroon is maar beperkt bevestigd. Er zijn nog steeds veel obstakels die een dergelijke evolutie in de weg staan. Het blijkt dat alleen de (verdere) introductie van verschillende waarschuwendende systemen alsmede voertuigvolg-systemen met beperkte deceleratiemogelijkheden relatief zeker is op korte termijn. Alhoewel meer geavanceerde systemen op de markt verwacht worden, op de middellange termijn, is het onzeker of deze zich verder zullen ontwikkelen. De implementatie van verdere automatisering van rijtaken in de volgende decennia, tot aan het niveau van de automatische piloot, blijkt zeer onzeker.

Op korte termijn wordt verwacht dat de implementatie van AVG gedomineerd zal worden door de markt in termen van het gedrag van potentiële consumenten. In het algemeen beschouwen deze consumenten ('snelweg' chauffeurs en vlootbeheerders) de eerste AVG systemen enigszins onaantrekkelijk om in hun voertuig(en) te hebben. Echter, het blijkt dat de aantrekkelijkheid van AVG systemen sterk samenhangt met de operationele kenmerken van het systeem alsmede de specifieke groep consumenten. Zoals te verwachten, beïnvloeden hogere prijzen de aantrekkelijkheid negatief en worden systemen die de reistijd en het brandstofverbruik negatief beïnvloeden aantrekkelijker gevonden dan systemen die dit niet doen. Waarschuwendende systemen genieten de voorkeur boven systemen die tijdelijk de rijtaak overnemen. Daarnaast blijkt er een behoefte aan

laterale (waarschuwendende) ondersteuning onder consumenten. Met betrekking tot verschillende marktsegmenten mogen vrachtwagenchauffeurs, wagenparkbeheerders en zakelijke rijders beschouwd worden als eerste mogelijke markten.

Gebaseerd op de bevindingen van bovenstaand onderzoek is het nu mogelijk een aantal beleidsaanbevelingen te doen die de toekomstige ontwikkelingen van AVG in een maatschappelijk wenselijke richting sturen. Een verdere continuering van het management van AVG onderzoek en ontwikkeling is belangrijk. Echter deze inspanning zou moeten veranderen van het ondersteunen van technisch ontwerpen en testen van geavanceerde prototypes naar het specificeren van de functionaliteit van AVG concepten vanuit een maatschappelijk perspectief.

De bijdrage in de komende twee decennia van ondersteunde AVG systemen aan algemene transport beleidsdoelen blijkt onwaarschijnlijk of mogelijk zelfs negatief. Publieke autoriteiten hebben de verantwoordelijkheid voor het specificeren van systeem prestatie-indicatoren en normen waaraan deze systemen zouden moeten voldoen om negatieve effecten op algehele verkeersdoorstroming en veiligheid te voorkomen. Dit zou meer richting geven aan de technische ontwikkeling van deze systemen.

Ook verdient de huidige wetgeving inzake aansprakelijkheid nadere aandacht om op de gevolgen van meer interveniërende systemen (bijv. botsingsvermijding-systemen) te kunnen anticiperen. De huidige onduidelijkheid van wet- en regelgeving moet opgelost worden daar dit leidt tot aarzeling onder betrokkenen. Een dergelijke vertraging leidt weer tot de ontwikkeling en implementatie van systemen met hoge R&D kosten.

Daarnaast dienen publieke autoriteiten te overwegen om in de toekomst meer betrokken te raken als implementator van AVG. Communicatie tussen voertuigen en tussen voertuigen en de weg kunnen de prestaties van AVG systemen mogelijk verbeteren en de introductie van meer geavanceerde systemen versnellen.

Tenslotte dient de acceptatie van potentiële AVG gebruikers verbeterd te worden. Hiervoor zijn verschillende strategieën mogelijk zoals bijv. demonstraties, pilots, en strategisch niche management (voor bijv. professionele weggebruikers). De adoptie van AVG technologieën door consumenten zal waarschijnlijk stimulerende maatregelen vergen afgestemd op specifieke behoeften en voorkeuren. Naast financiële prikkels kan gedacht worden aan het stimuleren van de implementatie van systemen die het brandstofverbruik en reistijd niet negatief beïnvloeden alsmede de bestuurder ondersteunen door middel van waarschuwingen in plaats van tijdelijke overname.

Samenvattend blijkt dat een actiever beleid inzake de implementatie van AVG mogelijk en gewenst is op verschillende wijzen. We hopen dat ons onderzoek de ontwikkeling van huidige en toekomstige beleidsstrategieën zal ondersteunen.



About the Author

Vincent Marchau was born in 1967 in Bruges, Belgium. He obtained his degree in Technical Mathematics at the Delft University of Technology in 1992. His Master's thesis focused on the algebraic description of gravitation fields. In the period from 1992 to 1994 he taught mathematics and physics within different institutes.

In 1994 he started to work within the Delft University of Technology and TRAIL Research School as a PhD researcher/assistant professor in Transport Policy and Logistical Organisation. Most of his work is focussed on research and lecturing activities in the field of Technology Assessment regarding Automated Vehicle Guidance. During his research he presented his work at several international conferences. Furthermore, he has published articles of his work in three international scientific journals.

He has further been involved in several scientific research projects under the auspices of a.o. the Dutch Ministry of Transportation, the Dutch Traffic Safety Board, the Telematics Institute, the Dutch Institute for Road Safety Research, and the Dutch Interdepartmental Organisation on Sustainable Technology Development. Within these projects his activities focused on researching implementation issues of Intelligent Transportation Systems in order to support public policy decision making.

Currently, his main interest involves the further development and application of appropriate methodologies regarding the field of 'Transport Technology Assessment'.



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