Speed support through the intelligent vehicle

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Summary

This report links different types of information about the position and perspective of speed management measures related to intelligent vehicles. Here a vehicle is defined as 'intelligent' if it obtains information from the environment (other vehicles, the infrastructure) and shares information with the environment, in order to assist the driver. The report presents scientific evidence of the predicted effects of promising intelligent vehicle systems for speed support. The evidence is based on state-of-the-art scientific knowledge, primarily dealing with safety, but also involving the other policy areas traffic efficiency and the environment. The report also gives an overview of key factors in the process of realizing the expected effects in practice. This is about uncertainties regarding reported effects, and about the question of effective deployment. For the latter, the report discusses the position of the different stakeholders, and potentially successful implementation strategies. Based on further insight into these key aspects, the report makes suggestions for further research and policymaking.

Intelligent vehicle measures within speed management

Speed management is a central theme in traffic management, aiming to optimize traffic in terms of safety, efficiency and the environment, by reducing speeding and speed differences in traffic. It has been estimated that in about 30% of fatal road accidents excessive speed is involved, making speed one of the crucial factors in road safety. There are different types of speed measures: infrastructural engineering, education, enforcement (the 3 E's), ánd vehicles. Preferably these types of measures interact well as part of a general road safety policy. The Dutch Sustainable Safety vision provides a framework for such a policy, with management of vehicle speed as one of its fundamental issues, and with a good perspective for the integration of traditional (i.e. the 3 E's) and new measures (e.g. based on intelligent vehicles). According to Sustainable Safety, speed limits are the core of the speed management system, and they must be safe and credible (matching infrastructural design and road network layout). Speed limits are preferably dynamic, instead of static, so that they are adjusted to changing traffic circumstances, such as weather, traffic density, pollution levels, and incidents. And last but not least, road users have to be well-informed about the limits.

Intelligent vehicles can perform tasks that conventional measures cannot do at all, or do less efficiently. First of all, they are an addition to current speed measures by helping to deploy the favoured speed limit system and increase the compliance with it. Furthermore, in-vehicle technology can support the driver in choosing an appropriate speed at all times and places, and in highly changing, specific conditions, that can not be accounted for in speed limits. Effect estimates have been described for four types of systems that contain (some of) these functionalities: various forms of Intelligent Speed Assistance (ISA), Advanced Cruise Control (ACC), Vision Enhancement Systems (VES), and black boxes. Much more literature was available for ISA and ACC than for the other two systems. Results of different types of studies were considered, noting that the evaluation of the systems in real traffic is still rare. Besides the difference in the amount of available literature, there

are also differences in the sizes and types of effects found in different studies. Therefore only indications can be given of what may eventually be achieved.

Effect estimates for ISA show the best results, though varying in type of feedback and intervention level (informing, warning, intervening, automatic control) and speed limit type (static, dynamic). ISA enables drivers to always have direct access to speed limit information in their car. The informing and warning types (also called SpeedAlert) actually can be seen as an additional feature of route navigation systems, and they recently started to be introduced on the market. Static informing ISA could possibly reduce fatal crashes over the whole road network by almost 20%. Speeding offences due to driver’s mistake or misjudgment are expected to drop considerably with these systems. For enforcement they can add to the credibility and effectiveness of speed checks. The best results, a reduction of fatal crashes with more than 50%, are expected from mandatory installation of dynamic automatic controlling ISA, in all cars, with no possibility to overrule. The predicted effects of other types are on levels between the two described here. Further compliance with the limits, especially for drivers who speed deliberately, can be achieved by the more restrictive ISA types. There are also relevant indications of a reduction in fuel consumption and harmful emissions (reductions between 4 and 11% have been reported for CO_2, NO_X, and HC), and of increased traffic efficiency, although research on this topic is still limited.

Most ACC studies show a significant decrease of speed variations due to ACC, leading to stronger indications for environmental benefits (decrease of fuel consumption and emissions) than for safety and traffic efficiency. The best road safety results of ACC, maximum accident reductions of more than 10%, are expected on motorways, in non-congested traffic, and in good weather. ACC effects on other road types needs to be further assessed, as well as the effects of different time headway settings. More positive effects are predicted for the next generation ACC, which will be more designed to detect hazards, e.g. by car-to-car communication, and to operate in congestion prone traffic. A combination of ISA and ACC may also be a good option. Where ISA reduces the mean speed and speeding, ACC may add to the system by reducing tailgaiting and speed variations. If individual cars supply their speed data to a traffic manager (e.g. through floating car data), it could give more reliable traffic information to drivers and an optimum speed advice for the given traffic situation.

The effect estimates of ISA and ACC assume 100% equipment rates, and do not take into account possible side effects, such as behavioural adaptation that may reduce the predicted effects. Risk compensation may e.g. lead to closer following; reduced attention may lead to slower reactions; overconfidence may result in insufficiently observing traffic circumstances; speed limitation may invoke frustration in the driver himself and frustration in following non-equipped traffic (possibly causing worse merging), as well as large speed differences between equipped and non-equipped vehicles. ACC usage on rural roads may lead to worse overtaking behaviour. More research should be done to assess the impact of these factors, e.g. with large field operational tests.

Based on qualitative observations, black boxes would give a considerable decrease of speeding. It also provides a possibility to give behavioural feedback to the driver, both positive and negative. VES has been treated as an example of Advanced Driver Assistance Systems (ADAS) which are not directly aimed at speed support, but with some reported effects on speed behaviour. The improved visibility offered by the system results in a higher mean speed in low visibility conditions. It should be further investigated what this means for the change of risk.

Deployment of Intelligent Speed Assistance

The largest safety effects and substantial effects in other fields are expected from ISA. To actually meet these expectations, adequate deployment is needed. This requires considerable effort, since so far there has only been little market activity. However, the basic technology is readily available and differences between stakeholder positions slow down the decision-making on ISA implementation. All this makes ISA an interesting subject for to investigating deployment processes.

Public authorities, the industry and consumers/drivers are the main stakeholders for ISA deployment, and good cooperation between them is necessary for successful implementation of ISA. More insight in the position (acceptance and preferences) of these stakeholder groups has been obtained, showing that they are not fully compatible yet, which requires further attention. On the other hand, e.g. the differences in opinions about safety are not that big, and not expected to seriously jeopardize further improvements and implementation.

All stakeholders show a general preference for systems that leave most freedom to the driver: i.e. voluntary warning ISA is most accepted and preferred among the stakeholders. The most promising ISA type in terms of expected safety effects, i.e. a mandatory automatically controlling form of ISA, is the overall least preferred form. Interestingly, it does not follow that mandatory introduction lacks substantial public support, as has been shown by a major survey among European car drivers in 2002. On the one hand, *consumers/drivers* begin to show resistance when personal freedom is at stake. On the other hand, there is considerable support when drivers think about effective measures, particularly if mandatory ISA were restricted to 30 or 50 km roads in urban areas, if it would operate within credible speed limits, and if the financial consequences are not too large. ISA acceptance among drivers could be further increased if the system helps to prevent speeding fines, saves fuel, and if there is an influential early adopter group that will serve as example for others. *Public authorities* are most interested in a cost-efficient contribution of the systems to policy goals. For road authorities the system's functional and technical reliability is important. Furthermore, they do not appreciate the general association of ISA with a mandatory, closed system of speed control. Therefore, the term SpeedAlert has been introduced for informing and warning ISA types to stress the importance of leaving full control of driving speed to the driver. While public authorities and consumers/drivers value safety as the most important outcome, for *the industry* factors relating to costs and financial risk are important considerations. Future research into stakeholder opinions regarding ISA should concentrate on an unambiguous methodology for the assessment of preferences of individual stakeholders (rather than of the average stakeholder), including changes in preferences over time. There should also be a strategy for research towards stakeholder acceptance, that deals with communication, socio-political developments, and past successes or failures.

An important aspect in creating a serious user demand for ISA will be to create an awareness of the benefits for the individual driver, combined with the collective interests for society as a whole. Upgrading current vehicles to intelligent vehicles may help to bridge this gap. Combined functionalities may result in an integrated driver assistance system, based on existing technology and supported by new technological developments. It can help to drive safely, avoid speeding tickets, optimize travel times and route planning, and drive in a comfortable and economic way. This combination of functions may make it easier to address the individual driver since he will get a more straightforward return on investment. Upgrading of the vehicle may also add to the product image and commercial attraction of the vehicle, while at the same time contributing to public goals.

Effective deployment of ISA requires good coordination, both at the national and at the international level. Central governments are in a good position to lead the coordination process. In most countries, they have the responsibility for the quality of the overall traffic and transport system. Furthermore, they have the overview of what is available in the market, how various applications can interact, and how ISA can be tuned to other speed management measures. Besides, ready-to-roll market models are rare. A good connection should be established with other national governments, the European Commission, and with local governments.

Potentially successful implementation strategies have been explored, searching for a good balance between market-orientated parties and government parties. There will be different accents in government roles in case of mainly market-driven or mainly government-driven implementation paths. In the first case, governments should focus on supporting the process by promotion and education. They should also watch over the balance between individual and collective interests, regulating and standardising where necessary, and they should establish a legal framework to deal with liability issues. Furthermore, they can facilitate progress by further developing digital speed maps (improving the quality, making it accessible), by being a partner in research and demonstration projects, and by offering financial incentives. In the second case, dealing with less popular, though effective systems, the government should take the initiative in raising support.

Better insight in the policy making process can directly influence the implementation scenarios. An innovative way of public policymaking for ISA has been described, dealing with uncertainties that surround a large scale implementation of ISA. Traditional incremental policy approaches can remain passive in response to these uncertainties, allowing developments to be largely determined by the flow of market forces. Several experts argue that policymaking should be more active and adaptive, allowing an early implementation, with the policy being adapted over time. An example has been described in which first a basic policy was defined, uncertainties were translated to vulnerabilities (which can make a policy fail), and signposts were installed to monitor their status and policy progress. Where needed, defensive or corrective actions would be performed, or the policy would be reassessed. The perspective of adaptive policymaking is promising, but some legal, political and analytic barriers still need to be overcome, before it can be put into practice. Further specification and testing of the approach for ISA should focus on systematic identification of the vulnerabilities. Scenario and simulation gaming may be used to compare adaptive policymaking to more traditional policymaking approaches. In this process scenarios should be envisaged in which in-vehicle ITS for speed support becomes increasingly important, co-existing with other measures and at the same time adding efficiency, and on the longer term possibly replacing some of the more traditional measures.

Finally

In general it has been shown that the role of intelligent vehicle measures in speed management can gradually become more prominent, in combination with traditional measures (infrastructural engineering, education, enforcement). Although large potential effects are forecast, and technological developments proceed, it is still uncertain if and when the systems will find a position among traditional measures, and make their promising perspectives a reality. However, relevant insight has been gathered, that can be used for further steps in research and deployment of the most promising systems.

For *research*, it is important to improve the reliability of effect estimates and to obtain better understanding of the deployment processes. This should result in more reliable predictions of penetration rates of the systems on the short and on the longer term. Eventually, this may lead to improved impact assessment, providing more knowledge to predict contributions of the systems to policy goals (such as in the *Mobility Policy Document*).

For *deployment*, a good basis would be the establishment of a generally accepted framework for ITS policy at the international, national and local level. All relevant stakeholders should participate, aiming at mutual cooperation. A road safety agreement for the implementation of ITS, with special focus on ISA, could be an appropriate first step; in any case in the Netherlands. Such an agreement may clarify and reduce uncertainties about the pace and direction of developments. Concurrent with such an initiative, first steps could be made to set up an adaptive policy for ISA.

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Foreword

This report is a deliverable of the Intelligent Vehicles project, which is part of the Traffic Management project within TRANSUMO (TRANsition to SUstainable MObility). TRANSUMO is a Dutch platform for over 150 companies, governments and knowledge institutes that cooperate in the development of knowledge with regard to sustainable mobility. TRANSUMO aims to contribute to a transition from the current mobility system towards a system that facilitates a stronger position in economic competition, as well as ample attention for people and the environment. The research and knowledge development activities have started in 2005 and will continue at least until 2009. Currently over 20 projects are being conducted within TRANSUMO. More information is available via www.transumo.nl.

The following researchers have contributed to one or more chapters of this report: Charles Goldenbeld (co-author of *Chapters 2* and *3*), Nina Dragutinovic (co-author of *Chapter 2*), Leonie Walta (co-author of *Chapter 3*), Vincent Marchau (co-author of *Chapter 4*), Peter Morsink (final editor, author of *Chapter 1* and *5*, co-author of *Chapters 2* and *4*). An overall review has been performed by Karel Brookhuis. Partial reviews have been made by Ingrid van Schagen, Fred Wegman (SWOV), and Sven Vlassenroot (TU Delft). All these people are thanked for their specific contribution. TRANSUMO is entitled to our gratitude for helping to make the composition of the present report possible.

1. Introduction

In the last decades, the traffic and transportation system has seen considerable advancements in information and communication technology (ICT*)* and vehicle technology. For instance, cars equipped with facilities such as radar, satellite positioning, route navigation, and communication technology have become increasingly common in recent years. And although equipment rates are still modest, higher rates are expected to be only a matter of time. These facilities are generally classified as specific types of *Intelligent Transport Systems (ITS)*, and many of them belong to the ITS subgroup of *Advanced Driver Support Systems (ADAS)*. The general perspective of ITS and ADAS is that they may significantly add to more efficient traffic management, in terms of improved safety, reliability, accessibility, and less harm to the environment (OECD, 2003). Especially speed management may benefit from what are called *in-vehicle speed support systems* (OECD, 2006). However, at the same time this perspective is mainly based on predictions of future scenarios, which introduce uncertainty about the actual effects of these systems that can be achieved within a road network and the pace of their introduction in the vehicle fleet (Wegman & Aarts, 2006). For a better insight in the current state of affairs of in-vehicle speed support systems, this report gives a survey of scientific evidence of predicted effects, links with transportation policymaking, positions of different stakeholders, and implementation strategies.

This introductory chapter sets the stage for the rest of the report. It first determines the position of the topic speed within traffic management (*Section 1.1*). *Section 1.2* describes how the speeding problem can be addressed from different angles, as part of the updated Sustainable Safety vision. Subsequently this chapter puts the intelligent vehicle measures into the perspective of speed management. *Section 1.3*. concludes the chapter with the main goal and the outline of the report.

1.1. Speed as a central theme in traffic management

Speed is a central theme in the traffic and transport system. Good speed management has a positive effect on safety, the environment, comfort and traffic efficiency (Van Beek et al., 2007)(OECD, 2006).

Safety

Excessive speed (above the speed limit) and inappropriate speed (for prevailing conditions) are causal factors in many accidents. It has been estimated that in 25 to 30% of fatal road accidents excessive speed is involved (TRB, 1998). However, the exact relationship between speed and accidents is complex and depends on several specific factors (Aarts & Van Schagen, 2006; Elvik et al., 2004). In general, it can be stated that higher speeds and larger speed differences among traffic participants increase the risk of accidents and severe injury. SWOV estimated that in the Netherlands the number of severe road casualties could decrease with 25%, if 90% of car drivers were to comply with the speed limits (Oei, 2001).

Environment, comfort and accessibility
Less speeding and fewer large speed differences are also beneficial for the environment. Energy consumption, noise, emissions of CO_2, NO_x and noxious dust all decrease at lower and more homogeneous speeds and by preventing frequent and abrupt accelerations. Interestingly, the comfort of driving increases at the same time. For accessibility and traffic flow optimization the situation appears less straightforward. There is some tension between the requirements of fast and those of safe traveling, since at first glance a higher speed reduces travel times and increases accessibility in free-flow conditions, but at the same time decreases safety. However, this tension is not as strong as it seems. A considerable part of the congestion is caused by accidents, and there are fewer accidents if speed is lower and more homogeneous. Furthermore, the maximum throughput of a road is generally achieved at a lower speed than in free-flow conditions (OECD, 2006). Traffic flows that become unstable, can also be stabilized by lower speed, resulting in higher average throughput.

Traditional speed reducing measures
Within speed management, safety measures are traditionally subdivided into engineering (infrastructure), enforcement and education (3 E's). Over time these measures have been successful. For example, the speed and safety effects of changes to the infrastructure have been demonstrated in several studies. For the Netherlands, Wegman et al. (2005) estimated that the construction of 30 km/h zones and roundabouts prevented about 5% of the total number of fatalities and in-patients in the period 1998-2002.

Using British data, Hirst et al. (2005) compared speed and safety effects of engineering measures and fixed speed cameras, using a study design that controlled for trends in crash rate and changes in traffic flow. They found a 4% accident reduction per 1 mph mean speed reduction for roads with a previous mean speed in the range of 30-35 mph. Furthermore, they found that engineering schemes including vertical deflections (speed humps, cushions) and those including horizontal features respectively resulted in a 44% and a 29% reduction of personal injury accidents. They also found a 22% reduction of personal injury crashes due to fixed speed cameras.

Despite the large number of speed control measures that have been taken, many people still drive with a speed well above the speed limit, regardless of the type of road or traffic circumstances (ETSC, 1995; SARTRE consortium, 2004). Violation percentages typically ranging from 40 to 50% on different types of roads are still very common, both in the Netherlands and in many other countries (Van Schagen et al., 2004)(OECD, 2006)(Achterberg, 2007).

The challenge
Supported by a growing sense of urgency, there is a call for further progress in tackling the remainder of the speed problem. An important challenge is to achieve bridging the gap between overall benefits for society and benefits for different stakeholders involved. Among those stakeholders, the individual traffic participants, mainly car drivers, are a crucial group. Getting the speed message across to individual car drivers is not an easy task, since most of the harmful effects of speeding occur at an aggregate, overall society level. For example, the likelihood for an individual to be involved in a speed related accident is not very high, and environmental damage is still rather abstract and far from the own backyard. Many drivers even experience speeding as

pleasant, exciting and challenging (Feenstra & Götz, 2002; Levelt, 2003). Besides, many drivers overestimate the gain of travel time that is actually obtained by speeding. For instance, just catching the green light at high speed can give the impression that one reaches the destination earlier, but in reality limited time is gained since most of the time will be spent waiting at the next red traffic light.

There is a strong sense that more benefit could be gained from the central position of speed management in the traffic and transport system. There are indeed challenging perspectives in which traditional and new measures are integrated, and different policy goals are better combined with individual interests. The next section describes a framework initiative as part of the Advancing Sustainable Safety vision, that can be considered as an example of a good starting point.

1.2. Sustainably safe speeds: a stepwise approach

The Advancing Sustainable Safety vision describes a national road safety outlook for the Netherlands (Wegman & Aarts, 2006). One of the general principles on which a sustainably safe traffic system is based, is harmony between traffic behaviour, infrastructure and vehicle characteristics. This should result in traffic participants complying with traffic rules because they perceive them as logical and useful. As a result, the inherent safety of the traffic system will increase considerably. As part of this vision, a stepwise approach to achieving safe speed behaviour has been proposed. In this approach the speed limit system has a central position as the legal basis of speed management.

The next sections will discuss the fundamental steps required to establish a sustainably safe speed limit system, and introduce points of attention and measures to increase the compliance with these limits.

1.2.1. *The speed limit system*

Safe speed limits
The safety level of a speed limit is determined by the function and design of a road, the allowed mix of road users, and the specific circumstances (e.g. weather conditions). A safe speed limit helps to prevent crashes in the first place, and helps to prevent severe injury in case an accident still occurs. Therefore, safe speed limits have to be based on 1) knowledge of the relationship between speed and crash risk on a given road type under given conditions, and on 2) biomechanical laws concerning injury tolerance of various road users. This, for instance, resulted in the sustainable safety requirement that the speed of motorised traffic needs to be reduced where motorised traffic mixes with vulnerable, slow traffic. For various traffic situations, Wegman et al. (2005) have proposed a system of 'safe travel speeds' for cars. In addition, the European project SpeedAlert has reported initiatives for better international harmonization of speed limits (SpeedAlert Consortium, 2004).

The safety level of a speed limit is considered a basic reference that should not be compromised. In addition, knowledge about environmental effects (pollution, noise) and traffic flow optimisation can very well be used as further input to establish a limit.

Credible limits
To invoke road users to actually adhere to the limits, it is essential that these limits are credible. This means that they are logical for the road user, i.e. they correspond to the expectations that a road's layout and traffic environment evoke (Van Schagen, 2006)(Aarts & Davidse, 2006). Due to variations in drivers' perceptions, it is difficult to find exact criteria for credibility, but a clear influence has been found for parameters such as road width and type of road markings. The driving simulator study by Van Nes et al. (2006) has shown that more credible speed limits clearly help road users to comply with them.
Dutch regulations aim at credibility, but several examples indicate that there is significant room for improvement. Correspondence between speed limits and road layout can be achieved by matching the layout with the limit or vice versa. On some roads the limit may need to be raised, whereas on others it may need to be lowered. Furthermore, it is important that where a limit changes, for example when leaving an urban area, road users should see a clear change in road layout.

Good information about the limits
Road users are often not aware of the actual speed limit at a given location (Schouten, 2005; Hendriks, 2004). This results in speeding, since good information about the limit is a basic requirement for compliance (Feenstra et al., 2002; Haglund, 2001). Apparently, the traditional way of communicating the limit with traffic signs alongside the road, or the density of these signs, is not enough. Examples to provide other, more frequent information are hectometre signs along motorways (indicating 100 km/h) and different types and colours of road markings. For the latter it is known that consistency and good communication to road users need more attention (Hendriks, 2004). Together with more credible speed limits, there is a big challenge for new ways of signalling to make the road user aware of the speed limit on a road at all times. In-vehicle signalling is a promising option, as will be discussed in more detail later in this report.

Dynamic limits
So far the speed limit system is referred to as a system of static speed limits, in which hardly any differentiation is made between day and night, weather conditions, traffic densities or specific circumstances. This static system is most common for all road types, except for some parts of the motorway network, where a type of dynamic speed limits is applied. The limit is changed in steps (90, 70, 50 km/h) in case of congestion, bad weather, or work zones, and communicated by Variable Message Signs (VMS). This differentiation is relevant for the entire road network and does not only affect road safety but also other policy goals. Furthermore, dynamic speed limits may add towards the credibility of limits, which is also related to varying traffic conditions. Therefore, for the near future it is recommended to further develop and implement a system of dynamic limits, taking into account local and current traffic conditions.

Physical speed reducing measures
When there is harmony between the (safe) speed limit, road characteristics and the environment, the role of physical speed reducing measures such as speed humps can be reduced. Their application should then be limited to logical locations, for example pedestrian crossings and intersections, fitting

within the layout of that particular road. This may considerably reduce the widespread opposition against these facilities.

1.2.2. *Increasing the effectiveness of the speed limit system*

If the steps, described in the previous section, are systematically taken, a level much higher than the current level of compliance with the speed limits can be achieved (Wegman & Aarts, 2005)(Van Schagen, 2004). However, it is questionable if this will be enough to ensure large-scale compliance with speed limits.

As long as road users can choose their speed themselves, there will always be a group that will frequently exceed the limits. Goldenbeld et al. (2005) for instance concluded that drivers in general tend to prefer a speed that is above the limit that they themselves consider to be safe. This may be due to overestimation of capabilities, which makes drivers think that safe speed limits do not necessarily apply to them, but only to other drivers. In addition, there is a specific group of drivers who enjoy a certain amount of risk taking by speeding (Zuckerman & Neeb, 1980; Clément & Jonah, 1984; Heino et al., 1992). These people apparently do not get incentives that are strong enough to ensure full compliance with the speed limits. Other incentives to comply with the limits, e.g. forms of behavioural feedback, tailor-made information or warnings, punishments or rewards, seem to be necessary to reduce speeding.

1.2.3. *The perspective of speed enforcement*

Intensified police enforcement is an extrinsic motivation for drivers to comply with speed limits. It confronts offenders with negative consequences (fines, other punishment) of their violations. The effectiveness of enforcement, as well as its limitations and its lack of credibility will be discussed below.

Effectiveness of speed enforcement
There has been various research on the safety effects of speed enforcement. Generally, reviews report positive effects of speed enforcement on speeding behaviour and the number of accidents (ETSC, 1999; Pilkington & Kinra, 2005; Zaal, 1994; Zaidel, 2002, HIrst et al., 2005). Goldenbeld & Van Schagen (2005) studied the effects of speed enforcement with inconspicuous mobile cameras at rural roads in the Dutch province of Friesland during a five year period. This study estimated a 21% reduction in injury crashes and severe casualties.
However, the effects of speed enforcement are by no means as clear cut as one would like. The extents of the reported effects of speed enforcement, for instance, vary largely. These differences relate to the type, intensity and location of the enforcement activities as well as the situation before the enforcement started. The Goldenbeld & Van Schagen (2005) study, like many other studies in road safety, had difficulty in correcting for several confounding variables and regression to the mean.

Limitations of speed enforcement
Despite these (generally) positive findings there are some clear limitations to the use of both automatic and manually operated speed enforcement methods. The one common thread in literature is the finding that speed enforcement effects are limited in terms of both time (e.g. Vaa, 1997) and

space (e.g. Christie et al., 2003; Hess, 2004). In general, only a small part of the total network can be supervised by speed checks. In the Netherlands, for example, less than 10% of the entire rural network is regularly checked for speed. When roads are checked by 24-hour speed cameras, the effects on speed and safety are often limited to a distance of 1-2 kilometres from the camera site. When visible and invisible mobile camera operations are used, the effects may cover a larger part of the road network, but this method uses up even more manpower, than is already used, which raises the costs considerably. The effects of visible camera operations along the roadside tend to dissipate after a couple of days (Diamantopoulou et al., 1998).

Elvik (2001) points out that after initial intensification of (speed) enforcement additional safety benefits from speed enforcement can only be expected when levels are increased once more. In practice this is not likely to happen. For instance, public resistance may grow, and social and there will not often be strong political support for further intensification after speed enforcement has been intensified before.

In addition, psychologist have pointed out that speed control by enforcement is essentially a negative motivational approach, relying on fear of punishment and reducing intrinsic motivation of drivers to conform to the law and/or alienating drivers from more positive motivation to conform to the law (e.g. Zaidel, 2000)

Improving the credibility of speed enforcement
Obviously, some form of speed enforcement will always remain necessary as long as drivers can choose their own driving speed. For a successful use of enforcement, there are several possibilities to improve its credibility, such as explaining the "why" of speed enforcement (e.g. safety, environment, quality of life), wherever possible supported by information about the effects. Furthermore, Van Schagen et al. (2004) recommend to focus control on deliberate and large offenders, achieving a higher chance of being caught, and to spend less effort on very brief and minor speed violations.
As part of the stepwise approach to achieving safe speed behaviour the reorientation of enforcement policy is identified as an activity for the short and medium term.

As part of technological developments, new enforcement methods of speed control are being developed, for instance in the European project PEPPER, Police Enforcement Policy and Programmes on European Roads (Martinez & Malenstein, 2007). An example is the recently introduced method of route section control, also called the average speed check, which may add to the credibility and effectiveness of speed enforcement. This method entails registering number plates on two points along the same road (Fokkema, 1994; Malenstein, 1998). By using the distance and time taken, the average speed over that road section is checked. The distinctive asset of this method compared with the usual methods of stationary speed control, is that the mean speed of drivers is checked over a longer stretch of road, and over a longer time frame. Large parts of the motorway may be equipped with this type of system, but it will not be feasible to use it on the entire road network.

In brief
Whereas speed control by police enforcement can be very effective to reduce danger on those parts of the road network which have road safety

problems and where changes to infrastructure are not possible, the method seems not suitable as a general instrument for speed control on the entire road network. For this reason, the Dutch Sustainable Safety vision also states that intensified conventional enforcement ideally comes in only when other measures for infrastructure, vehicle and road user behaviour are not adequate (Wegman & Aarts, 2006).

1.2.4. *The perspective of intelligent vehicle measures*

In the previous sections different aspects of the speeding problem have been discussed and steps have been identified to improve the design of the traffic system, with a central position for the system of speed limits. So far, vehicle measures have not taken a prominent position in speed management. Illustrative is the fact that vehicle measures are not considered part of the 3 E's. This is rather surprising since speeding and vehicle design and operation are directly related.

Relatively simple measures to reduce speeding by motor vehicles would be the introduction of physical limiters of the maximum speed, and the reduction of the engine power. Regarding engine power, there is the complication that it is not only related to maximum speed, but also to other operational requirements of the vehicle, such as driving up/downhill, being loaded/unloaded etc., which are not easy to compromise by manufactures. In most countries, speed limiters have been applied to trucks and mopeds, but not to passenger cars due to a lack of market demand, or political incentive. As a result of the lack of regulation, the average maximum speed and acceleration of passenger cars have increased significantly over the last decades (OECD, 2006). Although it still makes sense to aim for such restrictions, increased ‘intelligence’ of vehicles is more promising to prevent speeding as part of the stepwise approach towards a sustainably safe traffic system.

Wegman & Aarts (2006) and Morsink & Wegman (2006) describe a promising perspective of developments in the field of ITS. When it comes to vehicle operation and design, these developments combine ICT with advanced vehicle technology. In line with this observation, this report defines an intelligent vehicle as follows:

> *An intelligent vehicle is a vehicle that obtains information from the environment, and/or shares information with the environment, by means of sensors. An on-board computer processes the received information to make it relevant for the operation of the vehicle. Driver assistance is achieved by informing/warning the driver through a dedicated human-machine interface (HMI), or by directly intervening in the vehicle’s control system. The vehicle’s sensors are autonomous (e.g. radar) and cooperative. In the latter case, the vehicle communicates with other vehicles or infrastructure detectors (decentral control) or with a traffic management system (central control).*

An interesting feature of intelligent vehicles is their ability to add dynamics (adaptation to changes in time) and flexibility (adaptation to circumstances) to the current traffic system, which is highly statically organised. By responding to specific conditions, traffic can be made safer for a variety of road users in highly changing conditions (Wegman & Aarts, 2006).

Within speed management, intelligent vehicles can perform tasks that can not or less efficiently be done by conventional measures. The currently most relevant examples are discussed below, and they will be further described in the next chapter.

- First of all, intelligent vehicles effectively enable the operation of dynamic speed limits that are directly available at all times and places. This is the ultimate aim in the stepwise approach towards sustainably safe speed management (Wegman & Aarts, 2006). With actual, local speed limits available inside the vehicle, drivers can be warned when they exceed the limit or the vehicle can function as an intelligent speed limiter. Different forms of Intelligent Speed Assistance (ISA) are typical examples of this functionality, which can relatively easily be combined with route navigation systems.

- Furthermore, ITS technology can support the driver in choosing an appropriate speed for a local and temporary traffic situation. Appropriate here refers to the speed of individual vehicles, but also to the speed differences between vehicles, that should be low to achieve a more homogenous traffic flow. In many cases there may be time-critical situations that cannot be perceived well or be anticipated by the driver and that cannot be accounted for in the speed limits, even if they are dynamic. This makes large demands on providing the right information at the right time and the right place. Advanced Cruise Control (ACC) and Vision Enhancement Systems (VES), and Collision Warning and Avoidance Systems (CWAS) have characteristics that relate to this type of functionality.

- As indicated by the two previous examples, in-vehicle speed support can help to prevent drivers from making misjudgements, errors, and unintentional violations. This is expected to improve compliance with the speed limits. Furthermore, intelligent vehicles can prevent intentional speed violations, when they have an integrated enforcement function. Auto-policing based on in-vehicle ITS may make enforcement more effective and efficient by technologies such as Electronic Vehicle Identification (EVI) and black boxes (OECD, 2006).

The 'enrichment' of traffic information is another example of how in-vehicle speed support systems can be beneficial to different policy areas at the same time. This can be achieved if cars communicate their speed and position to a traffic management system (e.g. by a form of floating car data), that in turn gives more reliable information on congestion and more reliable route advice (see e.g. Breitenberger et al. (2004); Verkeerskunde (2006); Baskar et al. (2007)). Safety will benefit as well, presuming safety is accounted for as a criterion in the advice. Safety, traffic efficiency, and the environment will further and jointly benefit if the traffic manager determines an optimal speed advice or dynamic limit for the particular situation, and communicates that to the driver. At the same time, the car, detecting or in contact with other cars and infrastructural beacons, can continuously monitor the environment for any time-critical speed changes which are required. It can then advice the driver, and subsequently communicate with the traffic manager. This way, a level of speed management and network optimization could be achieved, that is hard to imagine without cars providing information at all times and places.

Bringing different functionalities together, intelligent vehicle systems can help to bridge the gap between interests of individual drivers and society as a whole (Morsink et al., 2006). In-vehicle speed assistance implicates upgrading of vehicles, e.g. to help the driver to drive safely, to avoid speeding tickets, to optimize travel times and route planning, and to drive in a comfortable and economic way. This combination of functions may make it easier to address the individual driver since he gets a more straightforward return on investment. Upgrading of the vehicle may also add to the product image and commercial attraction of the vehicle, while contributing to public goals at the same time (safety, accessibility, environment). Based on these developments a larger role for vehicle measures may open new doors to improve speed management.

The perspectives of in-vehicle technology in general are very promising (see e.g. OECD, 2003), and advancements in technology bring realisation of the high expectations more and more within reach. However, there still is uncertainty about the actual effects that may be achieved, e.g. regarding the interaction with human behavior, and the complexity of large scale implementation (European Commission, 2002). This is also the case for in-vehicle speed support. The overall penetration rate in the vehicle fleet is still limited at the moment, and therefore impact assessment can only be based on real-life evaluations to a limited extent. Furthermore, there is a variety of deployment strategies, that may lead to different expectations on the longer term.

1.3. Goal, TRANSUMO context, and outline of the report

1.3.1. *Goal of the report*

This report describes the position and perspective of speed support by means of the intelligent vehicle. It gives an overview of the scientific evidence of predicted effects of promising systems based on state-of-the-art knowledge; primarily dealing with safety, but also involving the policy areas traffic efficiency and the environment. The report also gives an outline of the key factors in the process of realizing the expected effects in practice. This concerns the uncertainties regarding reported effects, and the matter of effective deployment. The report intends to give a better insight in the position of the different stakeholders, and in potentially successful implementation strategies. Based on further understanding of these key aspects, the report intends to make suggestions for further research and policymaking.

The report mainly focusses on passenger cars. They represent the largest accident casualties group, and they have the largest involvement in crashes with slow traffic. However, this does not mean that speed support and control is not important for other motorized vehicles.

1.3.2. *TRANSUMO context*

The report is part of the knowledge investment programme TRANSUMO (TRANsition towards SUstainable MObility). TRANSUMO is a Dutch platform for over 150 companies, governments and knowledge institutes that cooperate in the development of knowledge regarding sustainable mobility. TRANSUMO activities have started in 2005 and will at least continue until 2009. More information is available on www.transumo.nl.

Within TRANSUMO, this study is done in the cluster programme Traffic Management which focusses on improving the road traffic system with respect to safety, throughput, reliability and environmental impact (Transumo VM, 2005). More precisely, in this cluster the report is a deliverable of the subproject 'Intelligent Vehicles'. The central objective of this project is to develop and value the potential of in-vehicle telematics, to support the deployment of promising systems, in the context of the goals mentioned above (Transumo VM, 2005). The Intelligent Vehicles project refers to all in-vehicle telematics applications in an intelligent road-vehicle system ranging from informing via actively assisting to actually taking over (parts of) the driving task by autonomous control systems, assisting the driver with the navigation, manoeuvring and control levels of the driving task.

1.3.3. *Outline of the report*

Chapter 2 describes expectations of certain in-vehicle speed support systems, i.e. ISA, ACC, VES and auto-policing (in-vehicle speed enforcement systems). It will particularly discuss their effect estimates, and drivers' attitudes towards the systems. The relevance of these examples is judged in the context of the Sustainable Safety vision regarding speed management, the availability of scientific literature, and in the context of the TRANSUMO Intelligent Vehicles project. Effects on traffic safety are described most prominently, but effects on other policy areas such as traffic efficiency and the environment are addressed as well. Uncertainties regarding the effects will also be identified. It should be noted that a system such as Electronic Stability Control (ESC), which may affect speeding behaviour as well, is not discussed here. This is mainly because ESC it is not considered an ADAS or telematics application, but an advanced vehicle dynamics system. Other ongoing research extensively addresses the effects of ESC (see e.g. Frampton & Thomas, 2007).

As ISA is identified as the potentially most effective system, the following two chapters will go into further detail about ISA deployment. *Chapter 3* describes stakeholder positions regarding the different types of ISA, and deals with attitudes, acceptance, valuation of outcomes and preferences of different stakeholders. *Chapter 4* explores ISA implementation strategies involving both market and government parties. The main focus is on possible positions of ISA in transport policy making. The transition from traditional to adaptive policymaking is explored, that could be better capable of facing the uncertainties that accompany ISA implementation. Finally, conclusions and recommendations are presented in *Chapter 5* and *Chapter 6*, linking to possible follow-up activities in the TRANSUMO project.

2. Expectations of in-vehicle speed support

2.1. Introduction

The current evaluation of in-vehicle speed support systems is mainly restricted to effects that they could potentially have. To show the state-of-the-art of these expectations, this chapter describes estimations obtained from the scientific literature about currently most relevant in-vehicle systems for speed support.

Table 2.1 presents a starting point based on the OECD (2003) inventory study. It summarises conservative and maximum estimations of injury and fatality reductions as a result of various technologies.

Technology	Percentage injury reductions – conservative estimates	Percentage fatality reductions – conservative estimates	Maximum reduction reported
Automated enforcement	8.3	4.4	50% of all related crashes
Advanced Cruise Control	1.4	0.7	5.9% of all crashes
Intelligent Speed Assistance	15	18	Mandatory – 59% of fatal crashes

Table 2.1*. Casualty reduction estimations (OECD, 2003).*

Table 2.1 shows the highest estimates for intelligent speed assistance (ISA). *Section 2.2* details the effects of different types of ISA, of which a considerable amount of research has been reported in the scientific literature.

Advanced Cruise Control (ACC) has a moderate effect according to *Table 2.1*. It is considered relevant though, because it is already on the market and vehicle equipment rates are increasing. The main findings are reported in *Section 2.3.*

ISA en ACC are both Advanced Driver Assistance Systems (ADAS) that directly affect speed. Besides, many other ADAS are considered to have an indirect effect on speed. In most cases this effect has not been addressed separately in research. However, for Vision Enhancement Systems (VES) some isolated potential effects on speed could be identified, as shown in *Section 2.4*.

Table 2.1 also shows potentially high effects for automated enforcement. This mainly concerns automated roadside cameras, but since in-vehicle technology may have a considerable added value, *Section 2.5* will further detail so called auto-policing. *Section 2.6* gives a concluding overview of expected effects of the discussed systems.

2.2. **Intelligent Speed Assistant**

2.2.1. *The system*

Intelligent Speed Assistance (ISA) is a general term for ADAS that aim to make drivers of motorised vehicles comply better with speed limits. The term Intelligent Speed Assistance is currently used in official communications of, for example, the European Transport Safety Council (ETSC), and replaces the original term Intelligent Speed Adaptation. In addition the term SpeedAlert is increasingly used for particular types of the system (informing or warning, see *Table 2.2*).

ISA systems establish the position of a vehicle (mostly using GPS), compare the current speed of the vehicle with the posted speed limit at a given location (mostly accessed through a digital map) and give in-vehicle feedback about that speed limit to the driver or restrict the speed of the vehicle according to the speed limit in force. Different types of ISA systems exist, which differ in their level of driving support and the kind of feedback they provide to the driver, as depicted in *Table 2.2*.

Level of support	Type of the feedback	Definition
Informing	Mostly visual	The speed limit is displayed and the driver is reminded of changes in the speed limit.
Warning (open)	Visual/auditory	The system warns the driver if he is exceeding the posted speed limit at a given location. The driver himself decides whether to use or ignore this information and to adjust his speed.
Intervening (half-open)	Haptic throttle (moderate/low force feedback)	The driver gets a force feedback through the gas pedal if he tries to exceed the speed limit. If applying sufficient force, it is possible to drive faster than the limit.
Automatic control (closed)	Haptic throttle (strong force feedback) and Dead throttle	The maximum speed of the vehicle is automatically limited to the speed limit in force. Driver's request for a speed beyond the speed limit is simply ignored.

Table 2.2*. An overview of different types of ISA systems according to the most common definitions.*

ISA can use three types of speed limits (Carsten & Tate, 2005):
1. Static speed limits – The driver is informed of the posted speed limits.
2. Variable speed limits - The driver is additionally informed about (lower) speed limits at specific locations (e.g. road construction sites, pedestrian crossings, sharp curves, etc.) and therefore the speed limits are dependent on the location.
3. Dynamic speed limits - The dynamic ISA system uses speed limits that take account of the actual road and traffic conditions (weather, traffic density). Therefore, besides depending on location, the dynamic speed limits are also dependent on time.

Since the early 1980s the effects of ISA have increasingly been researched. Reported studies include different methodologies and data collection techniques varying from traffic simulation, driving simulator, instrumented vehicles to field trials. A representative selection of these studies is discussed in this section, describing the effects on drivers' speeding behaviour. In most of the consulted studies the average driving speed and/or the mean driving speed (50-percentile speed), the standard deviation of speed (speed variance), and the percentage of speed limit offenders are used as indicators to show ISA effects. These indicators are the most commonly used statistical measures for speeding in European countries (SafetyNet, 2006). Subsequently, a state-of-the-art overview is given of how the effects on speeding behaviour relate to effect estimations on traffic safety, the environment, and traffic efficiency. The section concludes with an overview of the acceptance of the tested systems among drivers.

2.2.2. *Driving simulator studies*

2.2.2.1. Comte (1998)

In this simulator experiment there were 60 participants. The effects of an informing and automatically controlled ISA were investigated. The road network included urban roads, rural roads, and motorways with speed limits of 30, 60 and 70 miles/h (48, 96 and 112 km/h) respectively.

ISA effects on speed behaviour
The automatically controlled system was most successful in reducing excessive speed, particularly in urban areas. Also, there were additional positive effects like maintaining the lower speeds on curve negotiation and in areas with vulnerable road users. Without the support of the system, drivers were generally poor in speed adaptation.
The speed variance was also reduced, while there were no significant differences in travel times.

Other changes in driving behaviour
Although the automatic system had a positive effect on the mean speed and speed variance, there were also some changes in driving behaviour that could suggest negative effects on driving behaviour. In particular at the end of the trials, it was noticed that drivers spent more time at shorter headways, braked relatively late, and had a higher incidence of collisions. According to the authors this might be due to possible complacency and loss of vigilance among the tested drivers.

Acceptance of the system
The informing system found better acceptance among the drivers. Although drivers were more negative towards the automatic controlling system initially, they seemed to be less negative after having experienced it.

2.2.2.2. Hogema & Rook (2004)

This simulator study was carried out as part of the PROSPER project (Project for Research On Speed adaptation Policies on European Roads). The study aimed to examine how the effects of an intervening ISA system are influenced by the level of force feedback from the gas pedal.

A total of 32 experienced participants drove in an urban and a rural road environment (speed limits 50 and 80 km/h respectively) including various scenarios like free-flow driving, series of sharp curves, car following with and without possibility to overtake, etc. The ISA system combined a haptic throttle and visual feedback via LED's (light emitting diodes) integrated in the speedometer. There were two active ISA conditions, low and high-force ISA, differing only in the counter force that had to be applied on the accelerator in order to overrule the system.

ISA effects on mean speed
Table 2.3 shows that the system had a reducing effect on the mean speed in all tested situations, in free-flow traffic. On rural roads the use of high-force ISA resulted in a larger reduction than the use of low-force ISA. On urban roads no difference was found between the two types.

Road environment	No ISA	Low-force ISA		High force ISA	
		Mean speed	Difference in speed	Mean speed	Difference in speed
Rural	102*	94	-8	89	-13
Urban	55	52	-3	52	-3
* The values have been estimated from the original figures.					

Table 2.3. *Mean free-flow driving speed as a function of road environment and ISA condition (km/h).*

ISA effects on standard deviation of speed
Both types of system reduced variations in free-flow driving speed (see *Table 2.4*). This effect was mainly accounted for by the urban roads; no significant effect was found on rural roads.

No ISA	Low-force ISA	High force ISA
6.2	5.2	4.5

Table 2.4. *Standard deviation of the free-flow driving speed as a function of the ISA condition.*

Compliance with the speed limit
The percentage of drivers complying with the speed limit was higher in both ISA conditions compared with the control condition. This effect was stronger for high-force than for low-force ISA and it was stronger on urban than on rural roads (see *Table 2.5*).

	No ISA	Low-force	High force
Urban	31.3	56.3	65.6
Rural	12.9	21.9	34.4

Table 2.5. *Percentage of drivers in compliance with speed limit.*

Acceptance
In general, low-force ISA was accepted better than high-force ISA. The difference in acceptance can be attributed to satisfaction and not so much to

usefulness. There appears to be a trade-off between acceptance and effectiveness: the more effective the system, the more negative the attitudes toward the system.

2.2.2.3. Peltola & Kulmala (2000)

In this study an automatically controlled ISA system was investigated in a fixed-base driving simulator. 24 Participants drove on a 80 km/h rural road of which half of the route was slippery (friction 0.2 and visible differences on the road surface). Apart from the legal speed limit, a safe speed was also calculated based on curve radius and friction, and both speeds were input for the speed limiter. The speed limiter was only active on icy sections, and therefore it was called weather-related ISA or WISA. The other two experimental conditions included ‘normal’ driving with no extra information and driving with advanced driving information in the form of Variable Message Signs (VMS).

As a first observation it appeared that in the ISA condition none of the drivers ran off the road, while in both of the other two experimental conditions five drivers ran off the road.

Effects of ISA on mean driving speed
With the weather-related ISA the mean speed increased with 1.3 km/h compared with the 'no assistance' condition, In the VMS condition the mean speed decreased with 0.9 km/h compared with 'no assistance'. See *Table 2.6*.

No assistance system	Variable message signs	Weather related ISA (WISA)
63.3	62.4	64.6

Table 2.6. *Mean speed (km/h) for different conditions* (Peltola & Kulmala, 2000).

Effects of ISA on standard deviation of speed
The standard deviation of travel speed was calculated for icy road sections only. See *Table 2.7*. ISA reduced speed variation, but not as effectively as the VMS system:

No assistance system	Variable Message Signs	Weather related ISA (WISA)
12.3	11.0	11.8

Table 2.7. *Standard deviation of speed only on icy sections* (Peltola & Kulmala, 2000).

The higher mean speed with the WISA is explained by the fact that drivers increased their speed on non-icy sections of the road, adapting their behaviour to the system. Furthermore, the safe speed advice on the icy sections could be somewhat higher than drivers chose themselves being aware of the slippery conditions. Hesitation among drivers to comply with the advice could account for a higher speed variation.

2.2.2.4. Van Nes et al. (2006)

In this driving simulator study, the effects of a warning ISA system combined with a variation in the credibility of speed limits was investigated, using 41 test drivers. In a pre-simulation, the credibility level of the speed limit was determined by the intuitive speed choice of drivers without any support. There even were no traffic signs, only a well-considered variation of road design characteristics. This resulted in a series of road sections with speed limits with a varying level of credibility, that were subsequently applied in the experiment involving an ISA (21 drivers) and non-ISA (20 drivers) condition. Most attention was paid to 80 km/h roads, but 60 km/h and 100 km/h roads were also considered.

Table 2.8 shows the deviation of the average speed from the 80 km/h speed limit on road sections with different credibility levels of the limit, where a credible limit is considered not too low.

Speed limit credibility level	No ISA	(%)
Poor	8	-1
Moderate	1	-2.5
Very	1	-3.5

Table 2.8*. The effect of ISA and speed limit credibility on the average speed on 80 km/h roads (deviation from the speed limit in %). A minus sign means average speed is lower than the limit.*

As in much other research, the results of this experiment showed that ISA has a considerable reducing effect on the average speed. As a new observation, this effect was found especially significant in situations where the credibility of the speed limit was low. ISA also considerably reduced the time that the speed limit was violated with more than 10%. Furthermore, smaller speed variations were found when ISA was used, both for individual drivers over time and among different drivers.

2.2.3. *Instrumented vehicle studies*

2.2.3.1. Brookhuis & De Waard (1996, 1999)

Brookhuis and De Waard (1996, 1999) used a simulator and an instrumented vehicle for a series of studies investigating the effects of a warning ISA system. In the instrumented vehicle study, the experimental group consisted of 24 participants who drove in a built-up area, on A-roads and a motorway with different speed limits from 50 to 120 km/h. The continuous feedback display of the ISA system indicated the current speed limit and whenever this limit was exceeded, the colour in which the speed limit was displayed changed from green (“complying with the limit") to amber ("warning that limit was passed") and red (“10% over the speed limit”). If the limit was exceeded by more than 10%, not only the colour of the display would change from amber to red, but also an additional auditory warning message was issued. Unlike the experimental group, the participants in the control group received no feedback.

In the simulator study a comparable setup was used, including a condition with counterforce on the gas pedal. Additionally, in one of the studies a group of elderly drivers (60-75) was compared to young drivers (30-45).

Effects of ISA on mean driving speed
In general, the ISA with the continuous visual feedback had positive effects on speed behaviour. Especially in the 50 km/h zones, where subjects tended to violate the limit regularly, there was a clear speed reduction. The mean driving speed for the experimental group on these urban roads decreased from 56 to 51 km/h. The mean speed in the control group remained well over the speed limit during the trials at 55 km/h.

Effects of ISA on standard deviation of speed
The standard deviation of speed in the experimental group decreased with 0.5 km/h on the urban roads. There were no changes in standard deviation of speed in the control group.

Percentage of time driving above the speed limit
There are also positive effects of ISA on the proportion of time that drivers drove above the speed limit. In the experimental group that proportion decreased from approximately 26% to 21%, while in the control group it remained unchanged. The percentage of time that drivers drove more than 10% over the speed limit decreased in the experimental group for approximately 50% while there were no changes in the control group.

Acceptance of the system
Generally, the system was rated rather negatively (-1.04, on a scale from –2 to +2) on the compound satisfaction factor score (see Van der Laan et al, 1997), while the ratings on the compound score of usefulness for the system were slightly positive (i.e. +0.16). In the study with elderly and young drivers, an interesting difference was found between the acceptance of ISA before the experiment, when they were only informed by a manual, and after practical experience. *Figure 2.1* shows how elderly and young drivers differ with respect to their ratings on the usefulness (practical) and satisfaction (pleasure) of the warning ISA system.

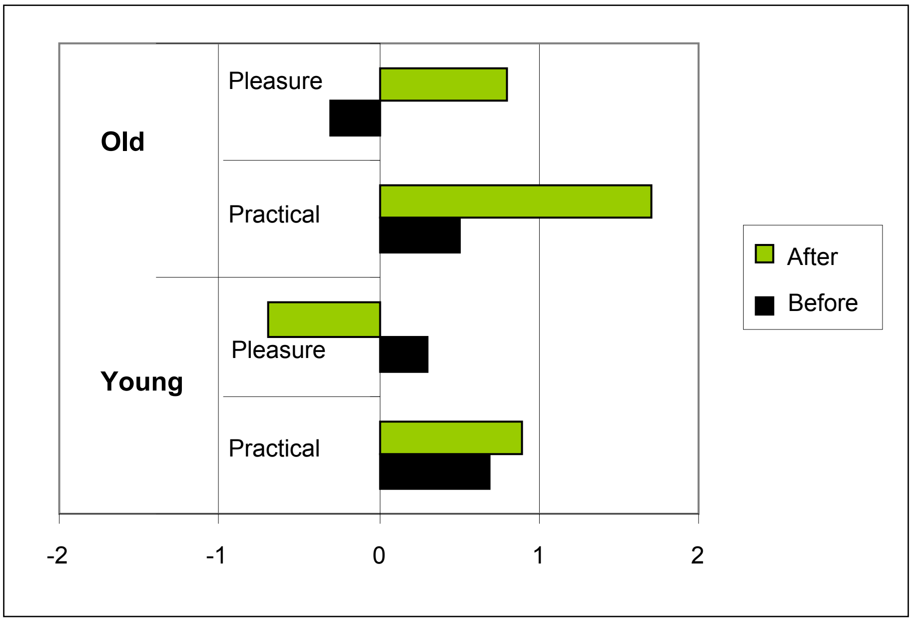

Figure 2.1 *Acceptance of ISA by elderly and young drivers (Brookhuis & De Waard, 1996/1999).*

In addition to what has been discussed here, the results of the Brookhuis & De Waard studies also show that the acceptability of ISA strongly depends on the specific feedback system used, with the continuous feedback being accepted best.

2.2.3.2. Paatalo, Peltola & Kallio (2001)

A total of 24 participants drove an instrumented vehicle on different road types, varying from motorway to residential area, where speed limits were 40, 60, 70 and 80 km/h. A warning ISA and an automatically controlled ISA were tested. Furthermore, a recording system was tested that functioned as a combination of an informing ISA and a black box. The following specifications apply to the different systems:

1. In the *warning ISA* the current speed limit was displayed and if the limit was exceeded, an auditory message was given. The message was then repeated every 10 seconds until the speed dropped below the limit.
2. In the *automatic ISA* the current speed limit was displayed as well. In case the speed limit was reached, a yellow spot was displayed to inform the driver and at the same time the gas pedal was blocked, obstructing a higher speed.
3. In the *informing/recording ISA* the current speed limit was displayed together with the diagram that showed how much the driver had been speeding so far. The speeding offences were divided into three categories: speeding offences less than 5 km/h, offences from 5 to 10 km/h above the speed limit and offences 10 km/h over the speed limit. Drivers knew that their speed behaviour was being recorded.

The situation in which only a route guidance system was active, was used as the control condition.

ISA effects on mean speed
Table 2.9 shows the effects on mean driving speed on roads with a 40 km/h speed limit.

Condition	Mean driving speed (km/h)
Only route guidance	42.6
Warning ISA	39.4
Automatic ISA	39.2
Informing/ recording ISA	40.6

Table 2.9*. Overall mean driving speed in different conditions.*

Looking at average travel times over the whole tested route, no significant differences were found between the different conditions.

Time spent speeding
The largest reductions of time spent speeding were found in the 40km/h and 80 km/h speed limit areas. However, these areas still have the highest percentage of time spent speeding
Each type of ISA reduced the time spent speeding, with the automatic system as the most effective one (see *Table 2.10*).

Condition	Time spent speeding	Reduction in %
Only route guidance	9 min	---
Warning ISA	3.5 min	61
Automatic ISA	2.3 min	74
Informing/recording ISA	5.7 min	37

Table 2.10*. Time spent speeding with different systems, where the time spent speeding when driving with route guidance only was used as a baseline.*

Acceptance of the system
The informing/recording ISA system was the most popular one. The warning system was not found enjoyable while the automatic system was rejected by the participants. For the automatic system, drivers felt the highest mental demand, time pressure, needed effort, frustration and insecurity. Again we see the trade-off between user acceptance and effectiveness.

2.2.3.3. Veilig Verkeer Nederland & SenterNovem study (VVN, 2006)

This study focussed on the effects of a warning ISA on speed limit violations. In total 30 participants drove the test vehicle on a route composed of different road types. The in-vehicle system was a functional extension of an after-market navigation system, immediately issuing a visual and auditory warning when the local speed limit was exceeded. The visual signal was maintained until the speed was lowered to the limit. The test drivers thought that they were volunteering for a general driving course, they did not know about the system or the goal of the experiment.

One of the main conclusions was that in 80% of the situations where the speed limit was exceeded, participants adjusted their driving speed after being warned by the SpeedAlert system (www.veiligverkeernederland.nl). In most cases this was done soon after the warning. For all road types, female drivers adjusted their speed more often than male drivers.

Regarding the acceptance of the system, most drivers were positive about the functionality of speed warnings. However, there were varying preferences regarding the specifications of the system, particularly the type of feedback.

2.2.4. *Field trials*

2.2.4.1. The Dutch trial (1999 – 2000)

The Dutch ISA trial (AVV, 2001) was carried out from October 1999 till October 2000, in a suburb of the city of Tilburg with 20 private cars and one bus equipped with an automatic type of ISA, using the dead throttle principle (automatic restriction of the fuel inlet). The experimental area included roads with 30, 50 and 80 km/h speed limits.

A total of 120 test drivers drove an equipped vehicle for 8 weeks. The first two of these eight weeks, ISA was switched off and drivers used this period to get used to the new vehicle. At the same time, the data about driving behaviour in this period served as a baseline for comparison between unsupported driving and driving behaviour when driving was supported by ISA.

The goal of the trial was to demonstrate the feasibility of ISA as a practical speed management instrument. Public acceptance and support for ISA was tested, and information was gathered about the technical functioning and effects on driving behaviour.

ISA effects on mean driving speed
The mean driving speed of the test vehicles is lower with ISA (see *Table 2.11*). Reductions in the mean speed for all three speed limits were significant, but the largest reductions occurred on the 30 and 50 km/h roads. The effects on 80 km/h roads were limited.

Speed limit (km/h)	Average speed (km/h)		Difference (km/h)
	Without ISA	With ISA	
30	28.9	25.1	-3.8
50	40,0	38.2	-1.8
80	57.3	57.0	-0.3

Table 2.11. *Mean driving speed and differences in mean driving speed of the test vehicles when driving without and with ISA.*

ISA effects on standard deviation of speed
Speed variations among the test vehicles are shown in *Table 2.12*. It clearly shows that the cut-off of high speed results in significantly lower speed

variations. Again, the highest effect was found for the 30 km/h roads, followed by the 50 km/h roads.

Speed limit (km/h)	Standard deviation (km/h)		Difference (km/h)
	Without ISA	With ISA	
30	10.4	7.5	-3.0
50	11.9	9.5	-2.5
80	16.5	15.6	-0.9

Table 2.12. *Standard deviation of speed and differences in speed variation of the test vehicles when driving without and with ISA.*

For both the 30 and 50 km/h roads larger differences in mean and standard deviation of speed were found on roads without other speed reducing measures (speed humps or speed cameras). The main reasons for the lower observed differences on the 80 km/h roads were speed cameras that were more frequently present on these roads.

The effects of ISA on the driving behaviour of bus drivers were similar to those for drivers of passenger vehicles: the mean speed and standard deviation of speed decreased when driving with ISA (*Table 2.13*).

Speed limit (km/h)	Average speed (km/h)		Difference (km/h)	Standard deviation of speed (km/h)		Difference (km/h)
	without ISA	with ISA		without ISA	with ISA	
30	30.9	27.2	-3.7	6.9	5.3	-1.6
50	34.9	34.4	-0.5	9.3	8.8	-0.5

Table 2.13. *ISA effects on the average speed and standard deviation of speed for the bus.*

Other ISA effects
Apart from speed effects the test drivers reported some positive and also some negative changes in their behaviour. As positive changes, almost 50% of drivers reported that they overtook less when driving with ISA than in their normal vehicles, 24% kept longer following distances and 32% said that they adopted a smoother driving style. However, the same percentage of test drivers (21%) reported decreased or increased irritation by driving an ISA vehicle in comparison to driving in their normal vehicle. Furthermore, the test drivers reported more irritation and more overtaking by non-ISA equipped vehicles in the test area.
It is interesting that the test drivers reported that they kept their normal driving style in areas where ISA was not operational. Therefore, the speed behaviour of test drivers in areas not covered by ISA remained unaffected by the mere presence of ISA in their vehicles.

Acceptance of ISA in the Dutch trial
The results about the acceptance of ISA by the test drivers are based on a restricted sample, i.e. 40 participants of the total 120. The majority (62%) of the drivers judged driving with the automatic ISA clearly less positive than

driving unsupported. Although driving with ISA was a positive experience for many, the test drivers perceived it as inferior to the usual, unrestricted driving. Furthermore, the appreciation of ISA differed for different speed zones. There were no differences between the acceptance of ISA on roads with 30km/h and 50 km/h speed limits, but it was highest for roads with an 80 km/h speed limit (Duynstee & Katteler, 2000).

Conclusions:
The Dutch ISA trial demonstrated positive effects of ISA on driving speed, where both mean driving speed and the standard deviation of speed decreased significantly when driving supported by ISA. These positive ISA effects were larger when the road conditions invite higher speed than the limit allowed.
The Dutch test drivers reported that they kept their normal speeding behaviour and driving style in areas where ISA was not functional. Furthermore, the test drivers appreciated ISA most on the roads with an 80km/h speed limit, while at the same time ISA effects were the smallest for this type of the road.

2.2.4.2. The Danish trial

In the spring of 2001, 24 test drivers took part in the Danish ISA trial. For six weeks they drove vehicles equipped with a GPS based ISA-system developed at Alborg University in Denmark (Lahrmann et al., 2001). As in the Dutch trial, in the first two weeks the ISA system was switched off, and this period was used as a baseline "before" period.

The local speed limit was shown on the display of the system and the measured speed of a vehicle was compared to the local speed limit. If the speed exceeded the local speed limit by more than 5 km/h, the system responded with a warning message (e.g. female voice says “50, you are driving too fast”), the display flashed and the red LED lighted up.

The results of the Danish trial show a speed reduction in the test period compared with the before period. Reductions of the mean speed were about 5 to 6 km/h in general (Nielsen & Lahrmann, 2005) but there were large variations in the speed reduction between individual drivers. Within the distribution of speed, especially a reduction of the highest speed values was found (indicated by a clear decline of the 85-percentile speed). This is also reflected in the magnitude of speed violations that were reduced from 9-13 km/h before, to 4-7 km/h in the test period. The decline was larger for rural than for urban areas.

2.2.4.3. The Swedish trials

Between 1999 and 2002 several large-scale ISA trials were conducted in Sweden. In the cities of Umea, Borlange, Lund and Linkoping approximately 5000 thousands vehicles were equipped with two types of warning ISA (Umea, Borlange) and an intervening ISA (Lund). In Linköping, both informative and accelerator pedal systems were tested on 150 vehicles (Biding & Lind, 2002). The following specifications apply to the different systems:

1. The warning system in Umea (4000 vehicles) issued an auditory and visual warning signal to the driver when exceeding the legal speed limit.

2. The warning system in Borlange (400 vehicles) had the same functionality as in Umea, but in addition informed the driver about the posted speed limit through a display.
3. The intervening system in Lund (290 vehicles) used an active accelerator pedal (AAP). When the driver reached the legal speed limit a counter pressure was applied to the pedal and a display informed the driver about the legal speed limit at the location.

ISA effects on average speed and speed violations
The data for average speed was collected in Lund and Borlange. The before measurement took place one month before ISA was activated and the after measurements approximately one month after the ISA activation. In order to examine ISA long-term effects, there was a second post-measurement in the last month of the trial period.

Test site (type of ISA and road types)	ISA effect on speed		
	Average driving speed, Pre-period (km/h)	Change in average driving speed, Post-period 1 (km/h)	Change in average driving speed, Post-period 2 (km/h)
Lund – Intervening ISA			
30 (km/h)	21.9	-0.8	-0.2
50 (km/h)	36.4	-1.1	-1.2
70 (km/h)	58.7	-2.0	-2.0
Borlange – Warning ISA			
30 (km/h)	25.3	-0.6	-0.6
50 (km/h)	38.7	-1.5	-1.5
70 (km/h)	58.7	-2.8	-3.0
90 (km/h)	84.4	-2.5	-3.4
110 (km/h)	97.3	-1.1	-

Table 2.14*. Average driving speed in Lund and Borlange entire trial area for the pre-period and two post-periods.*

Table 2.14 shows clear effects of ISA on the average speed on all road types, with the warning system having a greater effect than the intervening system.
Also, a (small) decrease of the mean speed was observed on the different road types .The effects were less clear though, since for instance on local roads the mean speed tended to both decrease and increase.

Table 2.15 shows that speed violations decreased significantly with ISA. The highest effects were seen on 50 km/h and 70 km/h roads. Judged by this indicator, the intervening system had somewhat larger effects than the warning system.

Test site (type of ISA and road types)	ISA effect on speed limit violations		
	Percentage of vehicle kilometres travelled above speed limit, Pre-period	Change in % of vehicle kilometres travelled above speed limit, Post-period 1	Change in % of vehicle kilometres travelled above speed limit, Post-period 2
Lund – Intervening ISA			
30 km/h	33.7	-14.1	-6.9
50 km/h	28.2	-15.0	-12.8
70 km/h	35.9	-18.1	-13.6
Borlange – Warning ISA			
30 km/h	33.8	-9.6	-3.4
50 km/h	31.1	-16.4	-11.8
70 km/h	21.4	-13.0	-9.4
90 km/h	25.1	-16.7	-11.4
110 km/h	12.4	-9.5	-7.4

Table 2.15*. Speed limit violations in Lund and Borlange for the pre-period and the two post-periods.*

Potential long term side effects of ISA (Hjalmadahl & Varhelyi, 2004)
From the test drivers who participated in the Lund trial, 28 drivers were selected to observe long-term side effects of the intervening system with the AAP. The selected drivers were observed twice. The first observation was carried out during the first test drive when AAP was not activated and before drivers had any experience with AAP. The second observation took place after at least six month of driving with the AAP. During this time AAP was activated within the test area. The test route was 33 km long and consisted of varying driving conditions that included all existing speed limits in Sweden. The used AAP was automatically activated and it was not possible for drivers to deactivate it. However, it was possible to overrule the AAP by applying five times more pressure on the gas pedal than normal.

After a six-month period of AAP use, participants improved their behaviour towards other road users. The percentage of correct yielding behaviour increased from 88% to 96%, and on arterial roads the time gaps increased when driving with AAP. The effects on other road types could not be found because the small number of car-following events.

However, next to these positive changes in driving behaviour after using AAP for a longer time period, there were also some negative changes found. For instance, some drivers forgot to change their driving speed when entering a new speed limit area in areas where AAP was not active.

The conclusion of this study is that although there are some signs of negative behavioural changes after using AAP for a longer period of time, the positive effects of AAP on traffic safety exceed these negative changes by far. This is due to the reduced speed in combination with other positive changes in car-following behaviour and improved behaviour towards other road users.

2.2.4.4. The Belgian trial

From October 2002 until January 2004, an ISA trial was held in the Belgian city of Ghent. In total 34 cars and 3 busses were equipped with an intervening ISA system based on the Active Accelerator Pedal (Vlassenroot et al., 2007). A total of 90 drivers took part in this field trial. The test area covered roads with speed limits of 30km/h, 50km/h, 70 km/h and 90 km/h. In the test area it was not possible to switch off the system, while outside the test area participants could choose whether to activate the system or not.

Results of the Belgian trial, depicted in *Table 2.16* show (relatively small) reductions in the mean driving speed and standard deviation of speed due to the ISA-system.

Speed limit (km/h)	AAP inactive		AAP active		Difference in mean speed (km/h)	Difference in standard deviation (km/h)
	Mean speed (km/h)	Standard deviation of speed (km/h)	Mean speed (km/h)	Standard deviation of speed (km/h)		
30	23.8	11.4	23.8	10.2	0.0	−1.2
50	30.1	14.9	31.6	14.6	0.7	−0.2
70	47.5	19.3	47.5	19.1	0.0	−0.2
90	69.1	19.3	68.0	17.6	−1.1	−1.7

Table 2.16. *Mean driving speed and standard deviation of speed when driving with and without AAP in the Belgian ISA trial.*

Table 2.17 shows a considerable amount of remaining speed violations in terms of the percentage of distance driven while speeding. This especially occurred in low speed limit zones.

Speed limit (km/h)	AAP inactive (%)	AAP active (%)
30	45.9	42.8
50	14.7	13.1
70	17.6	12.6
90	13.5	3.8
Total	16.3	13.1

Table 2.17. *Percentage of distance driven while speeding in the test area.*

The authors concluded that the counterforce exerted by the pedal was not strong enough to discourage drivers from exceeding the speed limit. Furthermore the authors mentioned other influence factors such as driving behaviour of other (non-ISA) drivers and discrepancy between the road design and the speed limit. Especially for the low speed areas a discrepancy was found between questionnaire outcomes, in which drivers declared to understand road safety benefits in these areas, and actual behaviour. Part of these discrepancy might be due to delayed driver reactions to speed limit changes while entering the low speed area.

2.2.4.5. The Australian trial

From February 2003 to March 2005 an on-road trial was organised by the Monash University Accident Research Centre and Ford Australia. In this trial 15 test vehicles were equipped with a warning ISA (visual and auditory signals) turning into an intervening ISA (upward accelerator pressure), if warning signals were ignored for more than 2 seconds. The vehicles were also equipped with a Following Distance Warning (FDW) system (aimed at preventing tailgaiting), a seatbelt reminder, a Reverse Collision Warning system (aimed to prevent collisions while driving backwards), and daytime running lights. A control group of 8 drivers was used. The control vehicles were not equipped with ISA and FDW. All 23 drivers drove at least 16,500 kilometres.

Table 2.18 shows reductions in mean speed, 85th percentile speed, maximum speed per trip, and standard deviation of speed, comparing the test period with the before period, for different speed limit zones and in free-flow driving conditions.

Speed zone (km/h)	Mean speed reduction (km/h)		85th perc. speed reduction (km/h)		Max. speed reduction (km/h)		Standard dev. reduction (km/h)	
	ISA	ISA + FDW	ISA	ISA + FDW	ISA	ISA + FDW	ISA	ISA + FDW
50	*0.7*	1.1	2.3	3.0	1.4	*0.8*	0.8	1.1
60	1.1	1.4	2.7	2.6	*1.1*	1.7	1.1	1.1
70	*0.9*	1.4	2.0	2.4	1.5	2.5	1.0	0.8
80	1.4	1.5	*2.1*	*4.6*	1.0	*1.4*	1.1	0.8
100	0.9	*1.2*	1.6	*1.7*	1.9	*1.5*	0.4	*0.3*

Table 2.18*. Reduction of mean speed, 85th percentile speed, maximum speed, and standard deviation of speed for cars equipped with ISA, or with ISA + FDW. The values in italics are considered statistically less significant.*

The ISA system reduced mean, maximum and 85th percentile speed, and reduced speed variability in all speed zones. ISA + FDW tended to have somewhat better results than ISA alone. ISA alone and ISA + FDW also reduced the percentage of time driven above the speed limit, while not increasing travel times. FDW alone did not significantly affect the speed variables.

There was no indication of increased risk taking associated with the use of the equipped vehicles. However, the positive effects persisted only while the systems were activated; drivers tended to revert back to old driving habits in the after period of the test.

2.2.4.6. General findings regarding ISA speed effects based on the consulted studies

The results of the various studies mainly point in the same direction. *Table 2.19* gives a qualitative summary of the studies that have been discussed so far.

Study	Methodology	Country	Effect on mean speed	Effect on standard deviation of speed	Speed violations
Comte (1998)	Driving simulator	UK	↓	↓	?
Peltola & Kumala (2000)	Driving simulator	FIN	↑	↓	?
Hogema & Rook (2004)	Driving simulator	NL	↓	↓	↓
Van Nes et al. (2006)	Driving simulator	NL	↓	↓	↓
Brookhuis & De Waard (1999)	Instrumented vehicle	NL	↓	↓	↓
Paatalo et al. (2001)	Instrumented vehicle	FIN	↓	?	↓
VVN (2006)	Instrumented vehicle	NL	?	?	↓
AVV (2001)	Field trial	NL	↓	↓	?
Lahrmann et al. (2001)	Field trial	DK	↓	?	?
Biding & Lind (2002)	Field trial	S	↓	↓	↓
Vlassenroot et al. (2007)	Field trial	B	↓	↓	↓
Regan et al. (2006)	Field trial	AUS	↓	↓	↓

Table 2.19*. Overview of the ISA effects on mean speed and standard deviation of speed in various ISA studies* (*↓decrease, ↑ increase, ? not investigated).*

The general conclusion is that ISA systems appear to have positive effects on the driving speed of ISA equipped vehicles: a mean speed reduction of approximately 2 to 7 km/h on average, as well as a reduction in speed variance and speed violations. The size of these reductions depends on the type of ISA, with more controlling ISA types being more effective.

2.2.5. *ISA effects on traffic safety, the environment and traffic efficiency*

It is not easy to make an accurate translation of the listed speed effects to real-life effects on safety, the environment and traffic efficiency. This is e.g. due to the experimental conditions of the consulted state-of-the-art studies, i.e. their scale and the extent to which they represent real traffic.

In addition to the methods discussed so far, traffic simulations can have an added value in upscaling to network effects and coupling of safety outcomes to environmental and traffic efficiency outcomes. Some of these studies will be referred to in the next sections.

2.2.5.1. ISA effects on safety

Based on the found reductions of mean speed, speed variance and the percentage of speeding, ISA systems can potentially achieve high reductions in the incidence and severity of road crashes (see e.g. PROSPER, 2006; Varhelyi, 1996; Louwerse & Hoogendoorn, 2004; Kievit & Hanneman, 2002).

Carsten & Tate (2005) presented an overview study comparing the safety effects of various ISA systems. They distinguished between an informing system and two types of automatic controlling systems:

1. The *informing system* displays the speed limit and reminds the driver of changes in the speed limit.
2. The *voluntary automatic control* system is a speed limiter based on a combination of a dead throttle and (a small amount of) active braking. It allows the driver to enable and disable control by the vehicle.
3. The *mandatory automatic control* system is a speed limiter based on a combination of a dead throttle and (a small amount of) active braking. The vehicle's speed is limited at all times and places.

Furthermore, a distinction was made between *static, variable* and *dynamic* speed limits, as described at the beginning of *Section 2.2*.

Their modelling approach to predict accident savings started with the assessment of a model for the relationships between changes in speed and changes in injury accidents (Tate, 1997). A single relationship for all roads was applied, based on the best estimate by Finch (1994), stating that a 1 km/h change in mean speed results in a 3% change in accident risk. This relation was used to create the estimates for the *informing system*. Though somewhat simplified, it appeared appropriate since differentiation per road category had little effect on the overall modelling results. Aarts & Van Schagen (2006) give a further review of the relation between speed and the risk of road crashes. For the *automatically controlling systems* the effect of a change in speed variation (high peak in the speed distribution at the speed limit) was explicitly accounted for in the estimation of accident risks, in addition to the Finch relation (Carsten & Tate, 2005).
The national database for Great Britain was used for injury accident data, and information on the mean speed and speed variance was obtained from the UK ministry of transport. Based on the accident data and the literature (including some of the studies discussed in the previous section), assumptions were made regarding the speeding behaviour with the different ISA systems.

The *informing system* was assumed to change the mean driving speed by 40% of the difference between the original mean speed and the speed limit issued by the system. The speed change of drivers with the *voluntary automatic control* system was assumed to be half of that of drivers with the *mandatory automatic control* system. *Variable* ISA was modelled to reduce speed in sharp horizontal curves on rural single-carriageway roads, and the *mandatory variable* system was assumed to reduce accidents in that situation with 41%. *Dynamic* ISA was modelled to affect accidents on rural roads, and the *mandatory dynamic* system would reduce accidents in darkness by 37%, on wet roads by 30%, and in snow by 57%.

Subsequently the accident savings were estimated/calculated, assuming a 100% equipment rate of the systems. The effects on injury accidents were used to calculate the effects on more serious accidents. *Table 2.20* presents the results of the best estimates per ISA type and crash severity.

System type	Speed limit type	Best estimate of injury crash reduction	Best estimate of fatal and serious crash reduction	Best estimate of fatal crash reduction
Informing	Static Variable Dynamic	10% 10% 13%	14% 14% 18%	18% 19% 24%
Voluntary automatic control	Static Variable Dynamic	10% 11% 18%	15% 16% 26%	19% 20% 32%
Mandatory automatic control	Static Variable Dynamic	20% 22% 36%	29% 31% 48%	37% 39% 59%

Table 2.20*. Best estimates of crash savings by ISA type and crash severity (source: Carsten & Tate, 2005).*

Table 2.20 shows considerable effects for all types of ISA systems. There is large variation though; informing systems appear to have a much smaller effect than mandatory automatic control systems. Also the effect of static and variable speed limits is smaller than dynamic speed limits. The most favourable effects are expected from the *dynamic mandatory automatic controlling* ISA, that would give a 36% reduction of injury crashes and a 59% reduction of fatal crashes.
It should be noted that the predictions in *Table 2.20* represent a 'best case scenario' as a 100% equipment rate and no behavioural adaptation to ISA have been assumed.

Oei (2001), Kraay (2002) and Regan et al. (2006) used Nilsson's formulas (Nilsson, 1981, 2004) to estimate reductions of injury crashes and fatal crashes.

Oei (2001) estimated the reduction in annual fatalities and serious injuries in the Netherlands, assuming a 100% equipment rate of a *static mandatory automatic control* system. Based on detected speed violations on different road types and using Nilsson's formula on the relation between speed and the number of traffic victims (Nilsson, 1981), Oei estimated the reduction to be 25% which is very much in line with the estimated 29% in *Table 2.20*. Using the same approach Kraay (2002) predicts a 34% reduction in fatal accidents and a 27% reduction in injuries as a result of large scale implementation of mandatory automatic controlling ISA on 30/50 km/h roads based on the Dutch trial in 2000.

Regan et al. (2006) used the power model (Nilsson, 2004) to estimate crash reductions from the driving data in the Australian trial. The combination of warning and intervening ISA would give reductions of injury crashes ranging from 2.8% (100km/h zones) to 5.8% (60 km/h zones), and reductions of fatal crashes ranging from 3.8% (100km/h zones) to 7.6% (60 km/h zones). If ISA was combined with following distance warning, additional 1 to 1.5% reductions could be achieved. These estimates could become considerably higher if truncations of peak speed could also be taken into account. Furthermore, it should be noted that the group of test drivers was considered rather conservative, already driving at relatively low speed without ISA.

OECD (2006) places a relevant remark at the results mentioned above, by stating that further research will be needed into actual speed variations during a transition period from low to high ISA penetration. Especially in case of the automatic controlling systems, there could be negative effects due to high speed variations between vehicles driving at the speed limit and other, non-equipped vehicles (OECD, 2006).

2.2.5.2. ISA effects on the environment

ISA is expected to be beneficial for the environment based on the estimated speed reduction and smoother driving behaviour by less speed variance. Environmental care concerns fuel consumption, CO_2 emissions, emissions of NO_x, noxious dust, and noise.

In general, a car driver can obtain considerable *fuel savings* up to 25 % if he keeps to the speed limit and adapts a smooth driving style (Feenstra & Van der Horst, 2006). The extent of the savings varies with the varying characteristics of engines and gear shifting, and therefore the exact relationship between fuel consumption and the mean speed is rather complex. Fuel consumption and related emissions are typically high in low speed congestion conditions, decrease with increasing speed, but from about 80 km/h on, considerably increase again. CO_2 is a direct product of burning fuel and as such *CO_2 emissions* can vary with a factor two between an extreme stop&go driving profile (very heavy congestion) and a driving profile for normal congestion (40-75 km/h) (TNO, 2001). Driving faster than 120 km/h on a motorway can result in 20 – 30% more CO_2 emissions compared with driving smoothly at 120 km/h. The relationships between speed and the *emissions of NO_x and noxious dust (PM10)* are less straightforward. TNO (2004) and AVV (2006) conclude that both decrease with a strict speed regime including lower speed limits. Furthermore, *tyre-road contact noise* dominates engine noise at a speed above 50 km/h, so decreasing speed on road sections with a speed limit higher than 50 km/h will generally reduce traffic noise.

Although the effect of ISA on the environment will directly relate to these general observations, the particular effects of ISA have not been researched much so far. For instance, the Dutch ISA trial (AVV, 2001) resulted in data that was insufficient to come to an indicative conclusion about ISA effect on emissions. The results of the Swedish trial in the city of Lund, showed that there were reductions in the emission volumes mainly for dual carriage ways and 50 km/h speed limits. The average reduction for CO volumes was 11%, for NO_x 7% and for HC 8%. On the other road types there were no significant changes and on arterial streets with a 70 km/h speed limit emissions increased (Varhelyi et al. 2004). In the Australian trial, Regan et al. (2006) found a decrease of fuel consumption and CO_2 emissions (both 4%) for a combination of ISA and FDW, not for both systems separately, and only in 80 km/h zones. Furthermore, significant reductions of NO_x (4%) and HC (7%) were found in 60 and 80 km/h zones.

Detailed micro-simulations are a promising method for further forecasting the environmental effects of ISA. In one such study (Liu et al. 1999) the ISA effects on network efficiency, fuel consumption and emissions were modelled for four networks: urban network in the morning peak, the same network in the off-peak, rural two-lane road and a motorway. They found that the total fuel consumption gradually decreased with increasing penetration levels of an *automatically controlling ISA* system. In case of a 100% equipment rate, predicted fuel savings were 8% for urban peak, 8% for urban off-peak, 3% for rural road and 1% for the motorway. Furthermore, they found that the emissions of CO, NO_x and HCs varied only by +/- 2% for all ISA penetration rates.

2.2.5.3. ISA effects on traffic efficiency

Specific research towards the effect of ISA on traffic efficiency is limited, but the general perspectives are good. Traffic flow theory, for instance, states that the maximum capacity of a motorway is reached at speeds below the free-flow speed (see e.g. OECD, 2006).

In the Swedish field trials the effect of ISA on travel times was found to be neutral (Biding & Lind, 2002). In the microscopic simulation study of Liu et al. (1999) the outcomes were somewhat further differentiated. They also found a neutral effect on travel time for ISA, expressed by the total travel time of vehicles in the network. But this only applied to high traffic density conditions, and could be explained by the fact that speed was already largely limited by congestion. However, in lower traffic density conditions, the travel time would increase with increasing ISA penetration rates, due to a lower average speed.

Hogema et al. (2000) carried out an explorative micro-simulation study of the effects of ISA in a lane-drop situation (from 3 to 2 driving lanes) on a motorway. They found more homogeneous traffic flow due to ISA judged by less speed variations within and in-between lanes, and a more balanced division of flow over the lanes. However, they also observed lower maximum traffic throughput at the bottleneck, which was probably due to a relatively high level of merging failures in the model. This relates to a lack of knowledge about lane changing and gap acceptance behaviour for ISA.

Other studies investigating the effects of homogeneous traffic flow on traffic throughput predominantly show positive results. For instance, the Dutch Drive Slow Go Faster project (or in Dutch *Langzaam Rijden Gaat Sneller – LARGAS*)) showed a considerable gain in travel time on 2x1 urban roads where car platoons were formed by lead vehicles that complied with the speed limit (Novem, 2003)(Verkeerskunde, 2006). AVV (2006) described the effects of a 80 km/h speed limit on motorways in heavy traffic urban areas, accompanied by automatic section control. A generally positive, but quite varying influence on traffic flow was found, although there were problems isolating the effects from other influence factors.

Besides, there is of course the effect that fewer accidents due to ISA will directly cause a reduction of congestion, since a considerable part of the congestion is due to accidents. Furthermore, the reduction of congestion also has a beneficial effect on the environment as mentioned in the previous section.

More research will be needed to further quantify specific effects for the different ISA types.

2.2.5.4. ISA side effects

Overall, the predicted effects of ISA are quite positive for traffic safety in particular, but also for the environment and traffic efficiency. It has to be noted though, that these predictions are based on generally rather optimistic presumptions. Several studies have identified side effects of ISA, both positive and negative, that could not or only to a limited extent be accounted for in effect estimates.

So the predictions that have been made so far, cannot be simply considered as realistic predictions because of the limited scale of the field experiments and the conditioned circumstances of the simulator studies. Although the Swedish evaluation project, which is likely to be the largest and most thorough field trial up to date, showed no evidence of negative side effects (Biding & Lind, 2002), there is concern about possible side effects. Adverse behavioural adaptation issues that have been reported include:

- Risk compensation behaviour: there are indications that drivers may compensate by driving faster on road segments where the ISA system is not active (Comte, 2000). When driving with ISA, they could also develop some risky driving behaviour like engaging in close following, accepting smaller gaps or braking relatively late (Comte, 2000).
- Diminished attention: ISA may result in reduction of attention for the road and traffic situation, when the system is not active. This diminished attention expresses itself in, for example, forgetting to slow down or to accelerate when entering a different speed zone, or in forgetting to use the indicator (Comte, 2000)
- Overconfidence: it is possible that using ISA could result in the driver completely relying on the speed limit indicated by the system, and insufficiently observing the real-time traffic circumstances.
- Feeling frustrated: increases in frustration and irritation have been found in several studies (Jamson, 2006). The speed limiting by ISA may produce frustration in the driver himself and in other following traffic (Várhelyi, & Mäkinen,1998; Comte, 2000). It may be reduced once highly reliable ISA systems have been developed and once ISA loses its novelty effect.

It is unclear whether these side-effects are short term responses to an unfamiliar system or whether they may persist with long-term use. This issue will only be resolved with long-terms studies of ISA usage (see e.g. Hjalmadahl & Varhelyi, 2004), including knowledge about the behavioural response of other drivers towards ISA drivers (see e.g. Duynstee & Katteler, 2000).

Furthermore, it has been stipulated that not all possible side-effects of ISA have been taken into account by experts. Jagtman et al. (2006) observed that field trails of ISA and other ITS applications had been focused on finding confirmation of expected effects which were mainly predicted to result from intended operating processes. In practice, safety-related effects of new ITS applications may also arise from unintended operating processes. Jagtman et al. (2006) identified a much wider variety of potential problems concerning the operation of ISA, than e.g. foreseen in the (42!) hypotheses of the Lund ISA project (Falk et al. 2002, Hjälmdahl et al., 2002; Várhelyi et al. 2002). They found these possible safety issues by using an ex ante assessment, based on a Hazard and Operability Analysis (HAZOP). This approach can help to define the full scope of problems that should be investigated by future field trials or other research.

2.2.6. *User acceptance of ISA by test drivers*

Acceptance is one of the critical issues for the potential success and effectiveness of ISA. *Chapter 3* discusses general public support and the acceptability for key-stakeholders, that are recognized as key issues for wide and successful ISA implementation. This section focuses on the acceptance of ISA by test drivers in the various studies. There seem to be three important factors for users' acceptance of the system: the type of ISA system, the driver's character and the type of road environment.

1) The ISA system itself – the 'acceptance versus effectiveness' paradox
The position of the ISA system on the informative-warning-control dimension seems to be one of the crucial factors that determine the users' acceptance of the system in question. A frequent finding in the research on ISA acceptance, is the trade off between effectiveness and the acceptance of the same system, i.e. the more effective the system is, the less accepted it will be. The more intrusive and controlling ISA systems are, the more positive effects they have on speed behaviour of drivers. However, these more effective but also more intervening ISA systems, at the same time turned out to be the less acceptable types of ISA systems in the various tests whereas other types of more voluntary ISA systems were more acceptable for the test drivers.

Besides on the type of the system (i.e. voluntary or intrusive), the acceptance of the particular system could strongly depend on the characteristics of the specific feedback system used. The study of Brookhuis & De Waard (1999) showed that the acceptability of the system could strongly depend on the mode of the used feedback. The continuous visual feedback was strongly preferred to auditory message. Field trials in Hungary and Spain investigated user acceptance of an auditory warning system (the so called BEEP system) and an AAP (see 2.2.3.3) intervening system (PROSPER, 2005). Both systems were perceived as useful and scored neutral on satisfaction. The Hungarian drivers however were more sceptical towards ISA in general than the Spanish. Furthermore, in Hungary three times the number of drivers preferred auditory and visual feedback over the haptic feedback (Falk et al., 2004).

Besides the importance of modality of the used feedback, the results of Hogema & Rook (2004) study indicated that also variations within the same modality could be crucial for user acceptance. Unfortunately, there is still not enough research that has systematically compared the effectiveness as well as the HMI characteristics between different types of ISA systems.

2) The driver
Not just the type of system but also the driver's character is important for the acceptance of the ISA systems. It seems that drivers whose speed behaviour would benefit most from ISA, least accept ISA. An example is the result of Jamson’s (2006) study where drivers who admit to speeding were less likely to engage a voluntary ISA system. Also, the results of the same study indicated that the age of a driver could also be important, with acceptability scores increasing as age increased, similar to the findings of Brookhuis & De Waard (1996).

Driver characteristics could especially be significant for the acceptance and furthermore for the real use of voluntary types of ISA with the danger of self-selection bias: it could happen that drivers, who "need" ISA the most, are least willing to use it. For example in the Hjalmdahl’s (2004) study, drivers who were willing to use these voluntary systems, already drove at a speed close to the speed limit, while those drivers who wanted to abort the trial after having used the system only briefly, were the ones who drove fastest without the system. Hjälmdahl (2005) further observes that initially more or less all drivers reduced their speed to the speed limit. After driving with the system for a while, the drivers who drove at high speeds without ISA started to speed up again. It is clear that not only acceptance but also the effectiveness of these system depends on (the characteristics of) the driver. Furthermore, these studies suggest that ISA with haptic feedback is efficient in reducing the speed of drivers who are speeding inadvertently, but does not reduce the speed of drivers who speed deliberately.

3) The road environment
The acceptance of the same system can differ between different types of road environment and related speed limits and driving speed, traffic densities, etc. Drivers' appreciation of ISA in the Dutch trial differed for roads with different speed limits. Although there was no difference in ISA appreciation between roads with 30 and 50 km/h speed limits, the acceptance was highest for roads with an 80 km/h speed limit. It is interesting that this result also points towards the 'acceptance–effectiveness' trade-off because the effects of the Dutch ISA were the smallest precisely for those 80km/h roads.
In a study of a voluntary ISA system, Jamson (2002) reports that drivers were willing to use the ISA system in low speed limit areas where other speed constraining factors existed. In higher speed limit areas, particularly where traffic density was low, and in speed transition areas, drivers were considerably less willing to use the system.

In general, research until now indicates that drivers do not have a very positive attitude towards these kinds of systems and that they favour normal, unsupported driving above driving with ISA. However, it is encouraging that several studies also indicated that there seems to be an increase in positive driver attitudes towards the system after having used it. After having some experience with ISA, test drivers thought more positively about the system in the terms of "usefulness" and "satisfaction" than they did before having any experience with the system.

2.2.7. *Ongoing developments regarding ISA*

In 2005, the first ISA systems (of the informative type) were introduced to the market (ETSC, 2006). Besides, there is a growing number of local initiatives of organisations that equip their professional vehicle fleet with ISA. In Sweden for instance, the Swedish Road Administration decided in 2005 to equip all their new vehicles with informative ISA, in order to support a wider deployment of ISA.

Further deployment of the system is most likely to go hand in hand with the deployment of other ADAS. Especially the integration with route navigation systems is promising. The vehicle fleet's equipment rate with navigation systems has seen a steep increase in the last couple of years. Many of these systems are already enriched with speed limit information to some extent (e.g. TomTom), or in some cases with locations of speed cameras. Furthermore, some vehicle models have manual speed limiters as a voluntary add-on. In the former situation, it actually means that the equipment rate of informative ISA may grow rapidly in the next decade. Developments such as Galileo can further add to the quality of such a system.

Accurate and reliable digital maps which include speed limits are necessary to strengthen the connection between ISA and navigation systems. In many countries the quality of these maps is still a problem. Sweden has a map that covers the whole country, and a small group of other countries, including Finland, Norway, the UK and the Netherlands, has made an effort to make such maps. These countries are also developing mechanisms to guarantee the quality of the maps. In the Netherlands, the speed limit map is publicly available on-line (www.maximumsnelheden.info). Visitors of the site are invited to check the information, e.g. regarding their own neighbourhood, and to communicate about errors or lacking information. New ISA pilot projects are also used to complement the map. For instance, in 2007 a project dealing with subjective safety effects of informative ISA in school environments, was started in the province of Noord-Brabant (Persbericht Noord-Brabant, 2007). At a European level further initiatives are taken to add functionality to the digital maps, including speed limit information, and improve their quality (eSafety Forum, 2005)(Wevers & Blervaque, 2004).

The use of ISA in urban environments may also have an effect on spatial planning. In a Dutch scenario study, large scale introduction of intelligent speed assistance in urban areas is expected to make physical speed reducing measures redundant (Loggers, 2004). Besides safety improvements, the study shows a perspective of more freedom in and better design of urban areas. This can only apply to a situation of high ISA penetration, which goes beyond only informing the driver. A collision warning and avoidance function will preferably also be integrated in the vehicle. Although these developments are ongoing, this is not likely to happen on the short term. Therefore, the study advises local governments to anticipate on this situation without neglecting attention for more traditional measures. The same type of conclusion was drawn by Eenink et al. (2001), stating that on the short term there will be no overlap between in-vehicle ITS and infrastructural measures, and therefore (local) governments should not wait for large scale ISA implementation and take more traditional measures for speed reduction on the short term. At the same time governments are advised to determine how they can contribute to the credibility of speed limits, and to examine possible replacement of physical speed reducing measures on the longer term.

The functionality of the ISA system can and probably will be continuously increased. For example, Duivenvoorden (2007) investigated an in-vehicle speed information system for green wave support. This system functions as an informative ISA by giving a speed advice to make use of the green wave on a particular road. In a driving simulator the system showed a decrease of mean speed and speed variations. The same type of application was also developed and demonstrated in the German Invent project (Invent consortium, 2004). Further shifts from ISA being just an individual speed support system to being part of the information chain for network wide traffic management, are foreseen as well. *Section 1.2.4* describes an example of more accurate and reliable traffic information.

2.3. Advanced Cruise Control

2.3.1. *The system*

Advanced Cruise Control (ACC) is an extension of the 'conventional' cruise control. It is called advanced, because it not only maintains the driver-set vehicle speed, but also adjusts the vehicle's speed to the preceding vehicle, and helps to maintain a pre-selected time gap to the predecessor. ACC uses a frontal radar/laser sensor to detect vehicles in front and subsequently adapts the speed and headway by controlling fuel flow or by braking slightly. Active braking can usually be performed up to 30% of the vehicle's maximum deceleration. In case a stronger deceleration is needed, the driver is warned by an auditory signal. Once the preceding, slower vehicle has moved out of the lane, the vehicle's speed will return to the pre-selected cruise speed. The system is also referred to as Adaptive Cruise Control or, sometimes, Intelligent Cruise Control.

Ten years ago, the first ACC systems were introduced to the market, as a rather expensive option for top-of–the line vehicle models. Today, ACC can be found on vehicles of various car manufacturers in a wide range of vehicle models (Bishop, 2005)(AVV, 2007). However, the equipment rate within the entire vehicle fleet is still barely 1%. Most of the ACC systems which now are available, function for speeds above 30 km/h, have a detection range of 120m to 150m, and allow for a manually set time gap between 1 and 3 seconds.

ACC was developed as a comfort and convenience system rather than as a safety system, mostly because of liability issues. However, it has often been hypothesised that ACC systems could also have positive effects on traffic safety, efficiency and the environment (see e.g. Golias et al. 2002). Several studies of ACC effects on driving behaviour were reported in the past decade. Most relevant studies are concerned with driving simulator experiments, whereas traffic simulation studies have also been conducted regularly. Unfortunately, well documented field operational tests are still rare.

This section has been organised differently than the previous section on ISA. The discussion of driving simulator studies is used as the basis (*Section 2.3.2*). Where available and appropriate, the simulator studies will be complemented with results from traffic simulation studies and field trials. In *Section 2.3.3* the effects on traffic safety, the environment and traffic efficiency will be discussed. *Section 2.3.4* gives a brief overview of the acceptance of the tested systems among drivers. *Section 2.3.5* describes ongoing developments regarding ACC.

2.3.2. *Driving simulator studies*

Several driving simulator studies investigated the changes in driving behaviour as a consequence of using ACC. The investigated ACC systems varied on specifications such as type of HMI, braking power and pre-set headway time. The studies also varied in the type of driving simulators used (e.g. fixed-base or moving-base), and traffic scenarios (e.g. motorway, other rural roads, free-driving conditions, busy traffic). The ACC overview study of Hoetink (2003) gives further details about the characteristics of most of the relevant driving simulator studies. It should be noted that these differences among the studies complicate a good comparison of the different outcomes.

Although studies included several driving behaviour indicators (e.g. headway, workload, lane-change, etc.), only the ACC effects on driving speed will be described here.

2.3.2.1. Effects on mean speed

Table 2.21 gives an overview of the studies discussed here and the differences in mean driving speed when driving without and with ACC.

Study	Simulator	Participants				Difference in *mean speed* ($ES_{um\ Speed}$) (km/h)
		N	Age	Driving licence (year)	Driving experience (km/year)	
Hogema, van der Horst & Janssen (1994)	Fixed-base	60	37.1* (21-54)	>3	>10 000	-3.85
Hogema & Janssen (1996)	Fixed-base	12	<60	>3		-3. 68
Nilsson & Nabo (1996)	Moving-base	30[1]	35.7* (23-57)	>5	>10000	-1.50
						0.90
Stanton, Young & McCaulder (1997)	Fixed-base	12	21	3.4*		0.00
Hoedemaeker (1999a)	Fixed-base	38	25-60	>3	>2500	8.00
Hoedemaeker (1999b)	Fixed-base	30	25-60	>3	>2500	-0.11
Brook-Carter et al. (2002)	Moving-base	32	16>60 16<25			1.00
Tornros et al. (2002)	Moving-base	24	40* (23-55)	(19*) 5-37	15 100* (2000-55 000)	0.10

Table 2.21. *The overview of the analysed studies and the differences in mean driving speed when driving without and with ACC.*

[1] In the Nilsson and Nabo study, there were originally 60 participants. Another 30 participants were engaged in an experiment where besides ACC, the influence of a mobile phone on driving behaviour was also investigated. The effects on driving behaviour of ACC only, were included in this analysis.

The differences in mean driving speed differ in size as well as in sign among the consulted studies. The positive signs refer to an increase in mean speed when driving with ACC as compared to driving without ACC, and a negative sign refers to a decrease. If all these differences are taken together, the overall average difference in speed between driving without ACC and with ACC is 0.1 km/h. From a road safety point of view, an increase in mean driving speed of 0.1 km/h can be considered negligible. Hence, it can be concluded that ACC has no effect on the mean driving speed.

However, bearing in mind the limited number of analysed driving simulator experiments (i.e. only eight) and the presence of outliers in obtained effects (i.e. 8 km/h difference in Hoedemaeker, 1999), it is necessary to analyse the somewhat contradictory effects of ACC on driving speed in more detail.

The driving simulator studies are clustered in two groups: a group with a decreasing and a group with an increasing mean driving speed. The average differences in driving speed are 2.5 km/h for the group with increasing, and -2.3 km/h for the group with decreasing mean speed.

Dragutinovic et al. (2005) found a systematic difference between these two groups. In all experiments with a relatively high increase of the mean driving speed (i.e. Hoedemaeker, 1999; Nilsson & Nabo, 1996 and Brook-Carter et al., 2002), a more supportive application than just a common ACC has been used. “Stop and go ACC”, which is able to decelerate the car to a complete stand-still, was used in Brook-Carter et al. and in Hoedemaeker’s experiment. Hoedemaeker’s ACC & Stop-and-go was capable of stopping in every possible situation. Nilsson & Nabo (1996) compared automatic with only informative ACC, which does not intervene in deceleration. It seems that those ACCs that support the driver at a higher level (allocate more tasks to the system in comparison to other types of ACC) and/or that support drivers within a wider speed range than common ACC, are associated with a higher mean driving speed. The bare types of speed support systems (common ACC) had no or a decreasing effect on mean speed.

2.3.2.2. Effects on standard deviation in speed

As for the mean speed, different studies found different effects of ACC on the standard deviation of speed.

It is to be expected that in low density traffic, where the driver is relatively free to choose his own speed, driving with ACC would result in a decreased standard deviation of speed. This is based on the observation that ACC maintains a pre-selected speed better than a human driver. The results of both Hoedemaeker (1999) and Tornros et al. (2002) confirmed this expectation. Hogema & Janssen (1996) did not find a difference in standard deviation of speed between driving with and without ACC. In high density traffic, most of the studies did not find significant differences in standard deviation of speed due to ACC. Only Hoedemaeker found a 6 km/h decrease in standard deviation (i.e. from 9 km/h to 3 km/h).

In 2006, a small scale field operation test was conducted in the Netherlands (AVV, 2007). In a 5 month period 19 test drivers travelled in cars equipped with ACC and a Lane Departure Warning (LDW) device. The test drivers (16 man and 3 women) were selected on a voluntary basis among lease drivers.

They used the cars for their normal daily mobility, on different types of roads and in different traffic conditions. Changes were observed between the pre-period, in which the systems were not activated, and the after-period, in which the drivers were free to activate or deactivate the system. As a general outcome of speeding behaviour, it was found that the drivers did not comply with the speed limits better when using ACC compared with not using ACC. Furthermore, speed in the after-period was somewhat higher than in the pre-period, on all roads, mainly concerning free-flow (>90km/h) and moderately busy traffic (70-90km/h). Variations in speed (and acceleration), however, were considerably smaller when using ACC.

2.3.3. *ACC effects on traffic safety, the environment and traffic efficiency*

2.3.3.1. ACC effects on traffic safety

The speed increases reported in the previous section could lead to a higher number of injury crashes, based on the relation between speed and the risk of road crashes, as described in *Section 2.2.5.1*. On the other hand, the decrease of standard deviation of speed could reduce the number of crashes. It is unclear how these effects are balanced, since most studies that tried to estimate safety effects of ACC did not isolate speed effects.

In the overview study of Hoetink (2003) effects on speeding behaviour are combined with effects caused by other driving behaviour. In normal driving conditions (low to moderate traffic density, dry and no extreme weather) no effect or a decrease of both driver speed and an increase of driver attention were found. The latter was judged by a decreased standard deviation of lateral position on the road. Therefore, in these situations, a small positive effect on driver safety seems more likely than a negative effect. In denser traffic however, driving with ACC resulted in a potential increase of the number of lane change manoeuvres, a higher manoeuvre velocity and a smaller accepted gap-distance when merging into another lane. These factors may all decrease traffic safety.

It is relevant to make a distinction between ACC usage on different road types. For non-motorway rural roads, Hoetink (2003) concluded that ACC may result in more dangerous overtaking. Additionally, ACC-drivers may have a delayed reaction to giving right-of-way when approaching an intersection. This may result in a deterioration of traffic safety, if ACC is to be used extensively on Dutch non-motorway rural roads (which generally have a high number of intersections). High traffic densities on Dutch motorways are another point of concern for safe usage of ACC on these roads. Overreliance on the system and reduced alertness may result in delayed reactions. On the other hand, adequate feedback by the ACC system, i.e. a good combination of slight automatic deceleration and a timely warning that the driver has to brake himself, may compensate for this behavioural change.

Hoetink (2003) makes a connection between driving comfort and traffic safety, using the results of questionnaires, that were issued to the test drivers of the analysed studies. The outcomes show that the participants experienced an increase in driving comfort. This is in line with the results of workload measurements with a secondary task or with heart rate variability, although the results of self-reported workload show some divergence. Still, these results indicate a reduced workload on both motorways and other rural roads. Provided that the capacity that is released is used for supervision of the traffic environment, this increase in comfort may lead to increasing traffic safety.

The Rij-assistent pilot study estimated positive safety effects for ACC (AVV, 2007). On motorways (through/flow roads), rural provincial roads (distributor road), and urban provincial roads (distributor road) respective reductions of 12,9%, 3,4% and 0,5% of all accidents was found, assuming all cars are equipped with ACC. These outcomes were based on other effects than speed, since a slight speed increase was observed, although there was no evidence that this was due to ACC. In short, the following procedure was followed.

- First, a selection was made of accidents that ACC may help to prevent. A classification of accidents was made based on causation factors described by Louwerse (2003), Louwerse & Hoogendoorn (2005). Accidents on road sections due to tailgaiting and abrupt braking manoeuvres were selected. The percentage of these accidents was determined per road type.
- Subsequently, the empirical data concerning ACC-on and ACC-off situations was analysed and compared. It was concluded that ACC would have a 90% effectiveness in reducing severe braking manoeuvres, and a 60% effectiveness in reducing very short (< 0.7 sec) time headways.
- The effectiveness was then corrected for the actual time that the system had been used on the different roads.
- Applying the derived effectiveness on the original share of accidents per road type, gave the estimated accident savings per road type.

Some notes on the validity of the outcomes were made. The province of Zuid-Holland was the experimental area , which is not necessarily representative for a larger area, such as the Netherlands. Self selection of the test drivers may have resulted in biased effects. Possible compensation behaviour and long-term behavioural effects (such as reduced overall attention) were not accounted for in the analysis, nor for external factors such as more motorway kilometres in the future. For instance, negative overtaking effects were assumed but not observed in the test.

2.3.3.2. ACC effects on the environment

ACC is expected to lead to a decrease in fuel consumption and a decrease in emissions, mainly because of the predicted decrease of the standard deviation of speed, which contributes to more homogeneous traffic flow.

Bose & Ioannou (2001) used both field experiments and simulation models to quantify the environmental benefits of ACC. In the field test, they used an ACC vehicle that trailed two other manually operated vehicles. The ACC vehicle drove with a pre-programmed speed profile i.e. aggressive-rapid-acceleration or non-aggressive smooth-acceleration. Drivers’ responses and vehicle dynamics, as they followed the lead vehicle, were recorded in the field trials and served as an input for the simulation model. The results indicated that 10% presence of ACC vehicles smoothed traffic flow in the case of rapid acceleration of the leading vehicle. This resulted in less fuel consumption and lower pollution levels than the manual driving.

Marsden et al. (2001) also used a combination of instrumented vehicle experiments and traffic simulations. They found a decrease of up to 52% of the standard deviation of vehicle acceleration, which indicates a considerable reduction of fuel consumption.

As part of the Rij-assistent pilot, models were used to calculate fuel consumption and emissions based on speed and acceleration profiles (AVV, 2007). Comparing ACC-on and ACC-off conditions, an average fuel reduction of 15% is estimated for all road types, and excluding congestion prone traffic (where ACC is rarely activated). This is due to the smaller variations in accelerations and speed. Comparing the whole pre-period with the whole after-period gives a reduction in fuel consumption of 3%. Comparing ACC-on and ACC-off, both CO, HC and NO_x emissions are predicted to decrease with 9-18%, with the highest reductions on provincial roads.

2.3.3.3. ACC effects on traffic flow

Several traffic simulation studies have been used to evaluate the potential impact of ACC on traffic flow (Hoetink, 2003). These studies differ largely with respect to the type of simulation models used (e.g. different behavioural models), traffic scenarios investigated, ACC system characteristics and ACC penetration rates. The different scenarios included free flow, transition from free flow to congested flow and vice versa, congested flow, and bottlenecks due to accidents. All scenarios modelled either two-lane or three-lane motorways, sometimes with ramps. The ACC systems differed in control algorithm, selected target headway times (ranging from 0.6 s to 3.0 s), maximum braking power (from 10% to 30% of the maximum braking capacity) and minimum operating speed of the system (between 30 km/h and 60 km/h).

All these methodological differences make comparisons between studies difficult, and the results should be treated with care. However, some trends were found regarding the effect of ACC on motorway traffic flow, as described below.

For low penetration rates (up to 20%), Demir (2002) found that ACC has no substantial effect on the dynamics of the traffic flow or on the relation between macroscopic traffic variables (e.g. average speed, density, travel time), irrespective of the ACC target headway time and traffic scenarios. Antoniou et al. (2002) found that the effect of ACC in free-flow conditions (high velocities and low traffic volumes) is hardly noticeable.

For congested traffic conditions and high penetration levels (40%-100%), it is generally found that with increasing ACC target headway time, average speed decreases and travel time increases.

Van Arem et al. (1996) and Minderhoud & Bovy (1998) found a decrease in average speed for ACC with headway times of 1.4 s and above, as a result of a collapse of speed in the fast lane. Furthermore, the standard deviation of speed increases, due to the occurrence of shockwaves. These shockwaves are generated when ACC drivers overrule the ACC system, because of lane change manoeuvres of other drivers, and brake manually.

It was found that the road capacity decreases for headway times larger than approximately 1.2 s, and increases for headway times shorter than 1 s. The estimated capacity increase then ranges from 4% to 25%, depending on the target headway time and ACC system used (see Minderhout, 1999). Broqua et al. (1991) estimated 13% gain in throughput with 40% rate of vehicles equipped with ACC using a target headway of 1 second.

Van der Werf et al. (2002) compared the impacts of autonomous ACC (AACC) and cooperative ACC (CACC, see 2.3.5) on traffic and found that AACC have only a small impact on highway capacity. In more detail, most gain was obtained by going from a 0% to 20% AACC penetration rate. An increase to 40% gives a smaller gain, and no additional capacity gain was forecasted with higher AACC penetration. Again, ACC traffic effects depended on the chosen headway. Minimum headway of 1.0s offered significant advantages in traffic flow whereas large headway of 2.0s resulted in significant disadvantages.

The Rij-assistent pilot studied the empirical data on speed variation, time headway variation, lane change behaviour and traffic distribution over driving lanes, to predict the effects of ACC on traffic throughput. A neutral effect was found, mainly based on the fact that average headway times did not change. This relates to the observation that the ACC was rarely used in congestion prone traffic (<70km/h, besides the system does not function below 30 km/h), and that the test drivers tended to select a headway time that they would also use without the system. However, it could not yet be determined what the effect would be at very high equipment rates of the system. Furthermore, it is anticipated that the headway time setting may become more dominant in case of a full range ACC (that also functions below 30 km/h) with the same headway time settings, which would possibly result in a throughput decrease (AVV, 2007).

2.3.3.4. General considerations regarding ACC effects

Much more than for ISA, different studies show different results for ACC. In general, ACC has a moderating effect on driving speed and the percentage of very short headway times decreases. However, there are also some issues of ACC use with drivers not always adequately reacting in critical situations which are reason for concern.

The mixed evidence does not allow to formulate a straightforward conclusion about the effects that ACC has on speed behaviour. These effects seem to be dependent on the type of ACC and the operational characteristics of various ACC types used in a particular study, that can result in contradictory effects on driving behaviour. When driving with ACC types that take over more of the driving tasks and offer more support to drivers in more critical situations (e.g. stop and go function, capabilities of a complete stop in every situation), drivers seem to adapt their behaviour by increasing their speed. More informative types however appear to show a reduced speed.

Contradictory effects on different policy goals could also be a result of variations within the applied systems. A reduction of very short headway times is beneficial for safety, but on the other hand low headway settings may increase road capacity.

Besides the significance of the type of ACC for its effects on speed, the traffic conditions (traffic density) seem to play a role in moderating these effects. When driving with ACC in low-density traffic conditions, it can be expected that the mean driving speed as well as the standard deviation of speed will decrease. On the other hand, when driving with ACC in high-density traffic conditions, it is to be expected that the mean driving speed will increase with also some indications of the decrease of standard deviation of speed, although indications for this are not as clear as in the case of low-density traffic conditions. Therefore, it appears that ACC systems can have a favourable effect on road safety if used on motorways outside rush hours.

A general conclusion as to what extent ACC will improve *traffic safety* and *road capacity* is difficult. For the *environment* there appear to be more indications for unambiguous benefits.

2.3.4. *User-acceptance of ACC*

Surveys among users of ACC vehicles generally show that drivers qualify ACC as a comfortable and useful system. The user survey by AVV (2004a) indicates that ACC would be more attractive to users if the acceleration and deceleration settings would match their own driving style better. Hoedemaeker (1999) found that acceptance could be further improved if drivers have more freedom to choose different following times.

The AVV (2004a) study also indicates that the operation of the system is not found difficult when adequate instruction has been provided. However, objective data about the process of learning to drive with ACC is very limited. In terms of time, it seems that it requires two or three weeks of intensive driving to get well acquainted with the system (Weinberg et al., 2001). Expressed in distance driven, it seems that approximately 400 km of driving with ACC is needed (Brouwer & Hoedemaeker, 2004). Unfortunately, learning to drive with ACC is not yet part of official driver training and it seems that most drivers do not read manuals. Therefore, the most common familiarization method remains the explanation by the salesman (Portouli et al. 2006).

The results of a one year ACC field operational test that involved over 100 selected drivers (Fancher et al.1998) showed that drivers did not use the system in dense traffic conditions while they choose to use ACC in approximately half of all their miles travelled at speeds above 35 mph (i.e. 56 km/h). Similar results have been obtained in the DIATS project where drivers expressed their willingness to use the ACC system in low-density traffic (Cremer et al., 1998), Rij-Assistent pilot (AVV, 2007).

2.3.5. *Ongoing developments regarding ACC*

Although ACC has been developed as a comfort system, OECD (2006) and Hoetink (2003) conclude that it may also evolve into a safety system, that integrates speed control, inter-vehicle distance control, collision warning, mitigation and avoidance functions. This section describes some ongoing developments regarding ACC, concerning combinations with other systems, upgrades of the ACC system itself, and the step from autonomous systems to so-called cooperative systems.

The somewhat limited functionality of ACC can be compensated for by combining functionalities into a more integrated driver assistance system. A first good step in this direction is a *combination of ACC and ISA*, in which the ACC is to take the speed limit as its default value. Where ISA reduces the average speed, ACC reduces tailgaiting and may further reduce speed variations. ETSC (2006) reports about a market initiative to launch an ACC with the ability to maintain mandatory speed. First production models were expected at the end of 2005.

The Rij-Assistent pilot used a *combination of ACC and LDW (Lane Departure Warning)*. Although the LDW was found much less effective than ACC, some of the test drivers reported an interesting positive integration effect. With ACC active, a slight increase in the variation of lateral position in the driving lane was found. This relates to a decrease of task load and may lead to a decrease of attention. The test drivers, however, claimed that the warning issued by LDW effectively compensated for this, and increased their alertness (AVV, 2007).

"Stop and go" systems are considered the next generation ACC, and they have recently become available. Unlike common ACC, this system has the possibility to slow down the vehicle to a complete standstill. To accomplish this, "Stop and go" ACC has to be capable of detecting other road users or stationary objects at a much closer range than a common ACC. ACC which operates from a standstill to the maximum speed is also called ' *Full-range ACC'*.

Predictive Cruise Control (PCC) refers to a system that accounts for variable speed limits, e.g. by issuing curve speed warnings. Like for ISA, these warnings can be generated by matching the car's speed and position (by the on-board navigation system) to the variable limit or advisory speed that is an attribute of the underlying digital map. The same functionality can be achieved by sending information from road side detectors to the car. In case of fixed warning locations, one can also use electronic warning signs along the roadside, e.g. by placing variable message signs before particular bends. In fact PCC can be considered a form of ISA functionality integrated in ACC.

Responsive ACC (RACC) represents a next step beyond the variable speed limits. It receives speed information/commands from a traffic operations centre, and subsequently adjusts the speed according to the received information. RACC can complement capabilities of the human driver, by responding to very fine changes in speed (e.g. increments of 1 km/h) and to make strategic speed adjustments. At the moment RACC only exists at the conceptual level (Bishop, 2005).

Further enhancements are foreseen by applying communication technology, which is increasingly integrated in the new generation of ADAS. These *cooperative systems* enable a further integration of functionalities and services by communicating with infrastructural detectors and other vehicles. This new generation of systems promises to further expand achievements of 'stand alone' ADAS applications and they are a subject of several research projects in Europe (e.g. INVENT in Germany, ADASE 2 , CarTALK, and PReVENT in Europe) and worldwide.

Cooperative ACC (CACC) is an advanced application that operates with communication between ACC-equipped vehicles, following one another in the same lane. The vehicles exchange information on deceleration, acceleration, speed and position, in such a way that each vehicle can 'look' a couple of vehicles ahead (Morsink et al., 2003), (De Bruin et al., 2004). The electronic horizon that is introduced this way increases safety by making better anticipation possible. Simulations indicate a better performance on traffic throughput, safety and emissions (Malone et al., 2003)(Malone & Van Arem, 2004). The system may eventually enable a decrease of headways between vehicles without negative effect on traffic safety. These short headways without traffic safety trade-off, could have a big positive effect on traffic flow. CACC with a 0.5 s headway would almost double traffic flow at a 100% penetration rate. The CACC market introduction is expected before 2010 (Bishop, 2005).

2.4. Vision Enhancement Systems (VES)

Vision enhancement systems help drivers to perceive visual information from the traffic situation in reduced visibility conditions (e.g. at night, with fog). The systems use infrared radiation to detect objects in front and present this information in the driver's field of view. Reduced visibility is an important contributing factor in road crashes, and the level of visibility is thought to influence drivers' speed choice. Better visibility may for instance lead to an increase of absolute speed as a result of levelling out driving task difficulty. On the other hand, interaction with the system may introduce additional work load, possibly resulting in a speed reduction.

These hypotheses make it interesting to learn about the expected effects of vision enhancement systems on traffic safety in general, and on speeding behaviour in particular. However, evaluation studies of the safety effects of VES are scarce, and this is even more so the case for their potential effects on driving speed. Furthermore, no reports about the effects on traffic flow and the environment were found.

2.4.1. *Driving simulator studies*

In the Nilsson & Alm’s (1996) driving simulator study, 24 experienced drivers drove a 40 km long test route in two visibility conditions: fog and clear sight (50m and 480m visibility respectively). The VES system generated a black and white picture of the traffic environment, which was presented on the monitor (17x12cm) positioned directly on the bonnet of the car, in the drivers’ central line of view.

The mean speed and variation in speed for each condition are presented in *Table 2.22*.

Condition	Mean speed (km/h)	Variation in speed (km/h)
Fog, no VES	60.5	9.2
Fog plus VES	90.9	12.3
Control (no fog, no VES)	104.6	10.1

Table 2.22. *Mean speed levels and speed variations.*

There was a big difference in the mean driving speed between driving in fog with and without VES (30.4 km/h). However, the mean driving speed when driving in the fog condition with VES was still well below the mean driving speed (i.e. 13.7 km/h below) when driving in the control (clear sight, no VES) condition.

In contrast to the mean driving speed that was affected by the level of visibility, there were no significant differences in speed variation between different visibility conditions.

In Stanton & Pinto’s (2000) study, 11 young drivers (average age 21 years) took part in a driving simulator experiment. The mean driving speed and the number of overtaking manoeuvres were compared between six driving conditions: daytime, night-time, night-time with VES, daytime with fog (50m visibility range), daytime with fog and VES, and daytime with fog and VES failure. The used VES was simulated by presenting a head-up display type of overlay in the driver’s central line of view. This was considered as a reasonable representation of how a VES prototype device functions.

The mean driving speed differed significantly between driving conditions, with a mean speed being lower in night and fog conditions than in daytime driving. Furthermore, driving speed was significantly higher in night and fog conditions with VES than without it. There were no significant differences in speed between the VES conditions.

The activation of the VES in reduced visibility conditions (i.e. fog and night driving) enabled drivers to continue driving at near daytime driving levels. It was concluded that the reduction of risk associated with the VES activation led to a risk compensation by an increase in driving speed, possibly restoring the pre-existing risk levels. Additionally, authors raised a concern about possible hazards in case of a combination of VES-equipped and non-equipped road users. Since this question was not addressed in the study, further research will be needed.

2.4.2. *General conclusions regarding VES*

From both studies it can be concluded that drivers increase their speed when supported by VES in reduced visibility conditions. However, this conclusion has to be taken with certain caution because of the limited behavioural data. Further research is needed to assess the effects on safety. It is also recommended to investigate effects on traffic flow and the environment.

It should be noted that the application of VES may make it more difficult to establish dynamic speed limits that include visibility conditions. After all, it may make sense to have a higher limit with support than without support. Or it may stress the need to eventually have a dynamic speed limit system only in conjunction with in-car support systems.

2.5. In-vehicle speed enforcement systems

Better speed limits supported by (ISA types of) in-vehicle speed assistance systems may go a long way in reducing part of the speed violations. Even the voluntary and non-intervening versions are effective in preventing drivers' errors in choosing the right speed, resulting in fewer unintentional violations. As shown earlier, these developments are well in progress, but it is also likely that the most persistent violators will be less affected. Eventually a 100% chance of being caught may be the only solution to tackle this problem of a relatively small group. This situation is not likely to be achieved with traditional enforcement (see *Section 1.2.3*). New vehicle technology can add to it with its crucial functional ability to monitor speed at any time or location. When these systems are integrated with enforcement functions, an objective chance of detection of nearly 100% can be realised (Rothengatter, 1991).

Depending on the types of systems (level of support) and practical experiences, in-vehicle systems may increasingly add to the efficiency of police enforcement (ETSC, 2006). This is especially the case if the in-car technology is explicitly dedicated to the enforcement of traffic rules. For example, *electronic vehicle identification (EVI)* functions as an electronic number plate. Originally developed to track stolen vehicles, it allows to follow a car over any distance, potentially improving current section control techniques (EVI Project consortium, 2004)(OECD, 2006).

Black-boxes that record driver behaviour can also be made part of the enforcement system and support it. Wouters & Bos (2000) have shown the effectiveness of black boxes to prevent rule violations and improve safety. The European SARTRE survey showed that 28% of over 24,000 interviewed drivers were "very much" in favour of black box systems that would provide evidence for enforcement about speeding or dangerous behaviour (SARTRE consortium, 2004). Black-boxes are sometimes called *Event Data Recorders (EDR)*, in case they only store information a couple of seconds before, during and after an accident. Langeveld & Schoon (2004) have shown that these systems are cost-efficient for larger transportation companies. Privacy considerations are the major issue surrounding a broader use of EDR. If this can be resolved, EDR may be expected to have a positive effect on speeding behaviour (OECD, 2006). It should be noted that these systems will make enforcement more effective, but they may also introduce a need for new forms of enforcement, as sabotage and malversation with the systems should be controlled as well.

Systems as EVI and black-boxes may very well increase the legitimacy of the limits, and, as a consequence, the credibility of the enforcement. The possibility to give behavioural feedback may also lead to rewarding good behaviour, which may add to the system’s effect.

In the end, a large scale application of technology such as automatic ISA, and black-boxes, that monitor the time and extent of the violation at all times and places, may result in a system of auto-policing that replaces police enforcement as we know it now. Zaidel (2000) sketches an Utopian view in which police enforcement of speeding is largely replaced by an alternative approach to speed management based on technology. His alternative approach consists of five positions:

1. Compliance with speed is associated with the vehicle unit rather than with the driver;
2. In-vehicle device and communication technology monitor vehicle speed at all times and keep a record of distance travelled while speeding;

3. Vehicles owners are given redeemable credits for distance travelled at requested speed and are surcharged for distance travelled while speeding;
4. Companies and fleet owners are evaluated by authorities with respect to the aggregated speeding performance of their vehicles; and
5. A marketing mechanism is created whereby non-speeding generates direct and indirect benefits to vehicle owners as well as to businesses. Businesses and institutions sponsor the benefits and develop operating strategies that favour non-speeding.

Zaidel mentions the following advantages of this system of speed control: self-enforcing, fair, immediate feedback, combination of carrot and stick, self-sustainable, and lessened need for conventional speed control.

Part of these items have already been taken up in government pilots or market initiatives. In the Netherlands, a small pilot called the Belonitor project, lasted for six months in 2005, and was setup by the Ministry of Transport. Lease car drivers received a small reward if the in-car system showed compliance with the speed limits and no tailgaiting (Wegen naar de Toekomst, 2005).

Insurance companies organise try-outs for black boxes to stimulate safe driving behaviour among groups with high safety risks. See e.g. the Dutch Pay As You Drive (PAYD) initiative within the Transumo project (Transumo, 2006). Insurance companies in Ireland and Denmark organised projects with recording ISA installed in cars of young drivers, in order to give them the possibility to reduce their relatively high premium if they complied well with the speed limits (ETSC, 2006).

Further evaluation of these in-vehicle systems to prevent rule violations are needed to assess their effect on the actual speed of drivers, and derived effects on safety, the environment and traffic flow.

2.6. An overview of in-vehicle speed support effects

This chapter has shown some large potential effects that in-vehicle speed support systems may have to improve traffic safety, the environment and traffic efficiency. Furthermore, it has shown some promising ongoing developments, that may add to these effects. It has also shown uncertainties regarding these potential effects that need to be further investigated.

Obviously, there are differences in the available data about the effects of particular in-vehicle speed support systems on driving speed and derived effects. Moreover, there are also differences in the size and type of effects found in different studies. Therefore, the overview of effect estimates as given in *Table 2.23* is only an indication of what may eventually be achieved. For the purpose of this table, in-vehicle speed enforcement systems are depicted as black boxes.

<table>
<tr><th colspan="2" rowspan="2">ADA System</th><th colspan="3">Traffic safety i.e. driving behaviour</th><th rowspan="2">User Acceptance</th><th rowspan="2">Environ-ment</th><th rowspan="2">Traffic efficiency</th></tr>
<tr><th>Mean Speed</th><th>Standard deviation of speed</th><th>Speeding</th></tr>
<tr><td rowspan="3">ISA</td><td>Advisory</td><td>+</td><td>+</td><td>+</td><td>+++</td><td rowspan="3">+ (?)</td><td rowspan="3">+ (?)</td></tr>
<tr><td>Voluntary</td><td>++</td><td>++</td><td>++</td><td>++</td></tr>
<tr><td>Mandatory</td><td>+++</td><td>+++</td><td>+++</td><td>+</td></tr>
<tr><td rowspan="2">ACC</td><td>‘Normal’</td><td>0</td><td>+</td><td>0</td><td>+</td><td>+</td><td>0 (+)</td></tr>
<tr><td>‘More advanced’</td><td>+</td><td>++</td><td>+</td><td>++</td><td>++</td><td>+</td></tr>
<tr><td colspan="2">VES</td><td>-</td><td>0</td><td>?</td><td>?</td><td>?</td><td>?</td></tr>
<tr><td colspan="2">Black box</td><td>+ (?)</td><td>+ (?)</td><td>+++</td><td>+</td><td>+ (?)</td><td>+ (?)</td></tr>
</table>

Table 2.23*. Overview of ADAS effects (+: positive effect, ++: considerably positive effect, +++: very positive effect; -: negative effect; 0: neutral effect; ?: effect not yet sufficiently known).*

Table 2.23 shows that the general prospects of ISA are most favourable, especially regarding safety. It also shows that the predicted effects increase with an increasing level of drivers' restriction to choose their own speed. However, at the same time the acceptance among drivers decreases with an increasing level of restriction.

Apart from the type of system (including the type of feedback system), user acceptance of ISA depends on characteristics of the driver. It seems that drivers whose speed behaviour would benefit most from ISA, accept ISA the least. Regarding the type of road, there are indications that ISA would be mostly accepted in low speed areas, and on 80 km/h roads.

The predicted positive effects for ACC are considerably less pronounced than for ISA. More positive effects are predicted for the 'more advanced' ACC, i.e. Stop&Go, Responsive ACC, Predictive Cruise Control and Cooperative ACC. The latter two may very well contribute most to a better future performance. A combination of ISA and ACC may eventually turn out to be a strong option. Where ISA reduces the mean speed and speeding, ACC may add to the system by reducing tailgaiting and further reducing speed variations.

It has become clear that more work needs be done to decrease the uncertainty of effects that may be expected in real life. Part of this should be done by advanced research regarding the functional impacts of the systems (e.g. by large field operational tests) and part of it should be done by increasing attention among relevant stakeholders, which should eventually lead to further implementation of the best and most promising systems. The latter is the subject of the next two chapters of this report.

Since ISA shows the best qualifications so far, since most basic technology for ISA is readily available, and since there is a considerable amount of reported activity on stakeholder positions and implementation issues for ISA, this system (with all its variations) is taken as the lead case from hereon.

3. Stakeholder positions regarding ISA

3.1. Introduction

The previous chapter discussed different technologies and their effects on speed and safety. It concluded that the largest safety effects, and substantial effects in other fields, can be expected from ISA. Cooperation between the main relevant stakeholders is very important to let these expectations become reality. Therefore this chapter describes stakeholder positions regarding ISA. In the literature two different approaches can be distinguished, (a) research into stakeholder acceptance and (b) research into stakeholder preferences. Although the concepts of preference and acceptance are closely related, they differ in perspective and in the way they are usually measured.

Preferences refer to what persons value more, given the fact that several options or outcomes are available. Usually preferences are measured by some type of ranking system. *Acceptance* refers to what stakeholders would be willing to approve or accept given the possibility that the introduction of a measure is being considered or planned. Often the question of acceptance is about a particular policy, measure or activity, instead of about more general outcomes. For example, very often acceptance is measured by questions such as: 'How strongly would you be in favour of measure X' or 'Do you agree or disagree with the introduction of measure X'. The perspective of acceptance is broader than that of preference; persons may accept an option or outcome that they do not rank highest. Consequently, research into stakeholder acceptance may give a more positive view on ISA than research into stakeholder preference.

It seems that, apart from very specific stakeholders such as researchers and insurance companies, stakeholder groups that are involved in ISA implementation can be categorized roughly into authorities/society, industry and users (e.g. ADVISORS, 2002, Walta et al., 2005). This categorization will be used throughout this chapter, because the results of most studies were aggregated to one or more of these three stakeholder groups. For a more complete overview of stakeholders see, for example, ADVISORS (2001).

This chapter is further organised as follows. *Section 3.2* presents results from survey research into stakeholder acceptance of ISA. *Section 3.3* presents results from studies on stakeholder preferences. These studies included rankings of outcomes of interest regarding Intelligent Transportation Systems in general, ISA policies and ISA operating characteristics. *Section 3.4* discusses the overall conclusions of these two approaches.

3.2. Acceptance by stakeholders

3.2.1. *Current situation*

Despite the expected safety effects, the implementation of ISA is not moving very fast. The current technological trend is to communicate the legal speed limit to the driver or vehicle by digital maps and GPS (see *Section 2.2*). This development can easily be integrated with the mass production of new navigation systems. However, as yet there is no consensus on the level of intervention to be adopted for large scale implementation. For instance, higher levels of intervention could be favourable from a societal point of view, but they limit the freedom of the individual driver. Pilots in several European countries, however, show a reasonable level of acceptance among test drivers (see *Chapter 2*). While the European Transport Safety Council (ETSC) and the eSafety initiative encourage stakeholders to place ISA on the agenda at the European level, the automotive industry appears to be reluctant towards ISA implementation (e.g. Reinhardt, 2004), which is illustrated by the absence of ISA in the roadmap for the automotive industry (CARS21, 2005).

These positions show that one of the largest barriers in implementation will be the differences of opinion between the many stakeholders involved in ISA implementation. These differences of opinion relate to the specific objectives and goals of stakeholders with respect to ISA. For instance, drivers in general dislike active interventions in their vehicle driving tasks if these are a limitation of driver freedom; for automotive industries, vehicle speed performance is often considered a selling point for their markets. Also, policymakers consider ISA a promising instrument for meeting their road traffic safety objectives but they have difficulties with the resistance shown by groups of drivers and the automotive industry. To find common objectives or policies that can be accepted by all stakeholders, knowledge is needed on how stakeholders value the results of ISA implementation policies, but is not yet available in a sufficient level of detail.

This section highlights some of the background of stakeholder acceptance towards ISA. The acceptance may change in time, as described by the innovation theory in *Section 3.2.2*.

3.2.2. *Theoretical notions about acceptance*

This section discusses theoretical views on the components of ‘acceptance’ and the factors that determine how acceptance may change over time.

It is too simple to expect car drivers to have unambiguous views or feelings about the implementation of new speed assistance. The social sciences provide ample evidence that people are not entirely consistent in the way they think, feel and behave. In the social-psychological literature, it is well-known that a change in general attitudes often does not correspond with a similar change in behavioural intentions (e.g. Fishbein & Ajzen, 1975). In a related field of enquiry, studies of the impact of mass-media campaigns show that effects on general problem awareness of societal risks are not consistent with effects on judgments of personal risk (Tyler & Cook, 1984). Some authors even speak of "an inertia" to behaviour change indicating that persons are mostly unwilling to change or give up comfortable lifestyles even though their knowledge and attitudes tend to change in a desired direction (e.g. Van Raaij, 2002).

In the specific area of acceptance of anti-speeding policies, the above-mentioned general theoretical formulations are confirmed by studies that show non-corresponding findings for different dimensions of acceptance of anti-speeding measures. A few examples. The Scottish anti-speeding

'Foolsspeed' campaign (period 1998-2001) was successful in changing attitudes and beliefs in an anti-speeding direction, but not successful in changing subjective norm, perceived behaviour control or behavioural intentions to speed (Stead et al., 2002; p. 5). A Dutch evaluation of a 30 km/h- publicity campaign showed that the campaign itself and its effectiveness were positively estimated by many respondents, but intentions to conform to the speed limit were not affected by the campaign (Feenstra & Götz, 2002).

In view of the fact that persons may tend to have conflicting views about a subject, researchers have conceptualised ‘acceptance’ or ‘acceptability’ as a multifaceted concept that has several components. Research in the field of road pricing distinguishes between three major factors that together determine the "social acceptability" of a traffic policy. First, drivers have to be aware of a problem or a danger arising from certain behaviour (e.g. Steg, 2003). Second, they have to consider a particular intervention or policy as effective, efficient and just, and appraise the intervention as positive or likeable according to personal, subjective norms (e.g. Ittner et al., 2003; Bamberg & Rölle (2003). Last but not least, they must be prepared to conform to the norms or guidelines set forth by the policy or intervention. More closely related to the subject of ISA, Menzel (2004) distinguishes between acceptability (of speed limits) and acceptance (of ISA). In his view, the acceptability of legal speed limits is as a pre-condition for the acceptance of ISA, i.e. the willingness to use ISA.

Over time, acceptance of new speed assistance technology can be seen as a dynamic process. Risser (2002) identifies eight major factors that will influence social acceptance of ISA over time. Three factors involve *communication*:
– the way the proponents communicate with the public or with relevant groups;
– the way politicians/decision makers or researchers communicate with each other;
– reporting by the mass media.

Three other factors have to do with *social-political developments*:
– the perceived interests in the decision making process (e.g. the freedom of the driver);
– changing awareness of social acceptance values (e.g. increased concern about the environment);
– the increased demand for public participation and involvement in political decisions.

Finally, two factors have to do with *the image of successes or failures of past projects* in this sphere and *the image of the potential project holder* who is responsible for introducing or advancing ISA on a larger scale.

It is important that in the future there is a strategy for acceptance research that deals with these eight factors.

Innovation theory (Rogers, 1995) offers another framework to understand the possible dynamics of social acceptance and implementation of ISA over time. This theory describes the process of getting an innovation – a product or behaviour – adopted, implemented and maintained over time. Diffusion of an innovation is thought of as moving from *awareness of a need* or an innovation, through *decisions to adopt* the innovation, to *initial and maintained use* (Rogers, 1995; Bartholomew et al., 2001; Oldenburg & Parcel, 2002). Looking at the implementation of ISA with this theory in mind, the first step is that drivers have to be aware of the risks or negative consequences that speeding may bring along (awareness), and they have to consider buying and using a speed assistance system (adoption). Subsequently, they have to decide using the speed assistance system (implementation). When they successfully move through these phases, they may end up in a situation where the use of the speed assistance has become routine practice (maintenance).

Rogers (1995) describes the process of adoption as a normal, bell-shaped distribution with five adopter categories: innovators, early adopters, early majority adopters, late majority adopters and laggards. *Innovators* are labelled as being eager to try new ideas while taking the risks of failure and loss. When compared to innovators, *early adopters* are characterized as being more respected by their network peers. Since they are perceived as taking deliberate, wise decisions, they are assumed to operate as role models for the early majority who generally take more time for their decision making regarding innovations. *Early majority adopters* have the gateway capacity to reach the average members of a social system. *Late majority adopters* and *laggards* are characterized as gradually more irresponsive to new ideas, while their innovation adoption is most determined by social or economic pressures. Of course, potential adopters can decide not to adopt an innovation. This decision can be either an active process or simply a passive failure to become familiar with the innovation and to decide.

Generally, the media are used to initially communicate innovations: the media increase awareness and people start to adopt the innovation. As more people adopt the innovation, and start to talk about their interest and experience, interpersonal communication becomes more important. More potent outreach and incentives are needed for late adopters and laggards, who have not adopted even though the innovation has been communicated and has been adopted by the majority of the population.

In general, we can derive the following conclusions from these theoretical perspectives on acceptance:

- Changing only one component of acceptance of ISA, such as for example attitudes, may not be enough to make any difference for other dimensions of acceptance (e.g. buying behaviour, the actual use of the system);
- Preferably ISA must be seen as an effective and likeable solution to a real problem;
- Since ISA is a support system for the system of speed limits, the credibility of speed limits themselves is important for a positive image of ISA;
- Successful diffusion of ISA amongst a larger public necessitates an enthusiastic group of early adopters that have positive experiences and inspire others.

3.2.3. *Road users' opinions about ISA*

In general, user acceptance of ISA systems that intervene in the driving task is less than acceptance of systems that inform or warn (Marchau et al., 2002; Regan et al. 2002; Wiethoff, 2003). Field trials in the Netherlands and Sweden have indicated that acceptance of ISA among test drivers increases with experience, but, on the other hand, technical problems with the system resulted in more negative attitudes. Furthermore, the acceptance of ISA within urban areas tends to be stronger than acceptance of ISA outside urban areas (Wiethoff, 2003).

Table 3.1 shows that, at the end of the nineties, both drivers and pedestrians rated the effectiveness of traditional speed reducing measures higher than automatically controlling ISA (Risser & Lehner, 1998). Pedestrians more often evaluated speed enforcement and higher fines for speeding as good or rather good than drivers did (differences for speed enforcement and for higher fines respectively: 72% vs. 61%, and 60% vs. 50%). Only 33-41% of drivers and pedestrians found automatic speed limiters in cars a good measure. Interestingly, more drivers and pedestrians evaluated automatic speed limiters without override as very good (20% and 27%). This is higher than for automatic speed limiters with override (13% and 15%). The implied message seems to be that governments should implement measures that will have substantial effects on speed.

Effective measures for achieving an appropriate speed	Very good		Rather good	
	Drivers (N= 630)	Pedestrians (N=564)	Drivers	Pedestrians
Speed humps	28%	35%	32%	32%
Stationary radar	28%	36%	30%	32%
More enforcement by police	31%	40%	30%	32%
Better information about the relationship between speed and accident risk	41%	38%	28%	12%
Automatic speed limiter in car that cannot be overridden	20%	27%	13%	14%
Automatic speed limiter in car that can be overridden	13%	15%	21%	19%
Higher fines for speeding	26%	35%	24%	25%
More frequent and perceivable signs	42%	36%	28%	30%
Clear and well indicated speed limits	49%	49%	29%	29%

Table 3.1. *Drivers' and pedestrians' opinions on speed reducing measures, including automatically controlling ISA (Risser & Lehner, 1998).*

In 2002, the SARTRE survey questioned over 24.000 drivers in 24 European countries about road safety measures, traffic behaviour, causes of accidents and new technological developments (SARTRE consortium, 2004). One of the questions in this survey concerned the perceived usefulness of a system that prevents one from exceeding the speed limit. The wording of this question implied that the system actually limits speed and is thus to be considered as a closed system. The question did not mention the speed limiter as part of a mandatory law, or as personal commercial purchase. It simply asked how useful it would be to have a certain device present in a car. *Figure 3.1* presents the findings for this question.

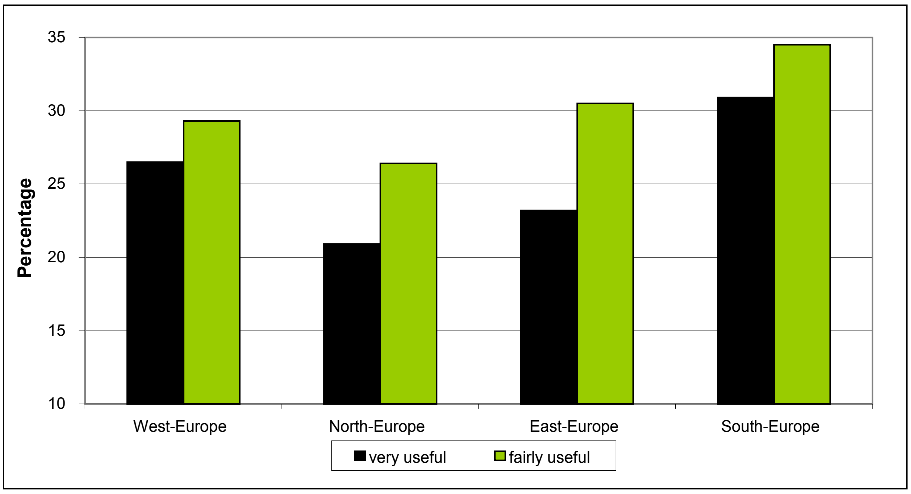

Figure 3.1. *Usefulness of devices that prevent exceeding the speed limit, according to European drivers (SARTRE consortium, 2004).*

As can be seen in *Figure 3.1*, slightly less than 50% of EU-drivers in Northern Europe, about 55% in Western and Eastern Europe, and about 65% in Southern Europe would find such a system very or fairly useful. These percentages present a fairly large amount of acceptance given the fact that the question referred to a closed, interfering system.

Interestingly, the SARTRE survey also asked drivers whether they would be in favour of fitting devices to cars that prevented drivers from exceeding the speed limit. This question covered the same device (a closed, interfering speed limit system), but now the question was phrased in terms of a general measure. *Figure 3.2* presents the percentages of EU-drivers that would be very or fairly in favour of such a measure, split out for four European regions. When phrased in terms of a general measure, the acceptance of closed speed limiters was even somewhat higher than on the previous question, with about 50% of drivers in Northern Europe being in favour, about 60% in Western and Eastern Europe, and about 70% in Southern Europe.

Given that both SARTRE questions concerned the closed type of speed limiters, the level of public acceptance found was unexpectedly high. It is possible that the SARTRE-3 questions show a too optimistic picture of public acceptance since the questions do not mention any costs at all for the public. Even if a measure would be decided top-down by central authority, there would be costs involved for drivers. Thus, it is conceivable that reported acceptance would be lower, once drivers were made aware of personal costs involved. Other research presents some insights into these matters.

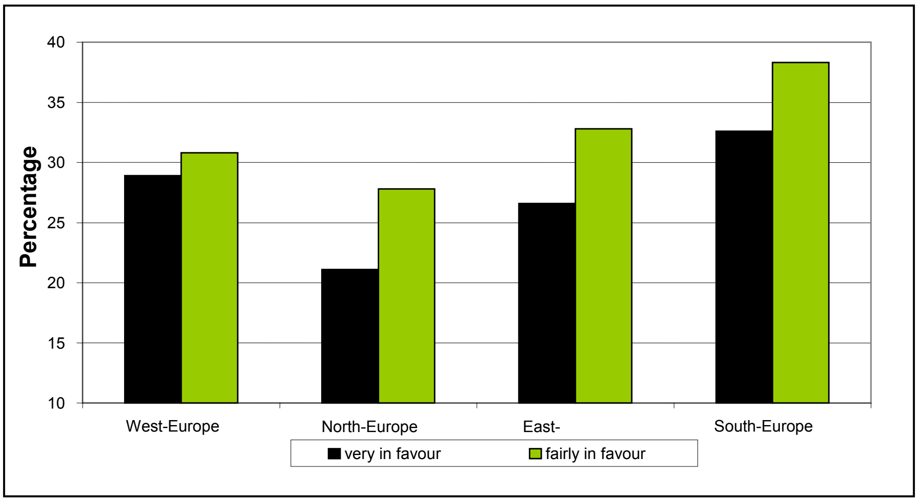

Figure 3.2. *Acceptance by European drivers of devices that prevent exceeding the speed limit (SARTRE consortium, 2004).*

Piao et al. (2005) report results from surveys on ISA in three European cities with different sample sizes (Brussel, N=245; Oslo, N=301 and Southampton, N=491). These were the most important results::

- In all three cities, there was strong majority support (>60%) amongst respondents for an informative, warning type of ISA, but very little support for ISA (< 30%) with a haptic accelerator or mandatory ISA without possibility of override.
- In Brussels and Oslo, some 50-60% of drivers believed that ISA would bring safety improvements, and 53%-56% said they would consider buying an ISA system for their next car.
- In Southampton, 68% of the drivers who would consider buying ISA would accept a prize below € 300 (£ 200)
- In the hypothetical situation where speed limits are aggressively enforced, the attractiveness of the ISA systems increases so that more drivers in Oslo would be interested in the system.
- Up to 85% and 71% of the drivers said they would like to use ISA systems in residential areas in the UK and Norway, respectively. Belgian respondents favoured the use of ISA in the entire urban area.

3.2.4. *European industry opinions about ISA*

Various actors in the industry are involved in making speed assistance systems part of future cars, the international automotive industry, the traffic industry, the OEM's (Original Equipment Manufacturers), interest parties (EUCAR, ACEA), service providers, road managers, insurance companies. In general, the automotive industry is reluctant towards speed assistance systems that are mandatory and/or intervening (Marchau et al, 2002). The term ISA itself is preferentially not used by representatives of American and European automotive industry. However, some automotive industries develop speed assistance functionalities as part of ACC or navigation systems. The automotive industry co-operates with the Speed Alert project (SpeedAlert, 2003) which states explicitly that the driver shall remain in control of the vehicle's speed at all times. In reaction to the term ISA, the term SpeedAlert is increasingly used as a sort of ideological alternative to ISA.

With respect to the market introduction of ISA-systems, representatives of the automotive industry see consumer perception of utility as problematic and rate the product image as rather low (Marchau et al. 2002). The industry does not consider corporate image to be a critical (long term) success factor, since it is expected that eventually all industries may be involved in some ISA-type functionality and the benefits of being a supplier for early adopters is considered to be small.

Menzel (2004) studied the conditions for the implementation of speed adaptation technologies in Germany. The author concludes that the implementation of some type of ISA in Germany before 2010 is nearly impossible. The political opposition from the automobile industry, the problems involved in collecting data from federal states, and the potential problems with product liability are considered powerful barriers on the short term. The author mentions the following particular barriers for the German car manufacturers: the world-wide sales of high-performance cars (power output of more than 125 KW), the principle that the drivers should always be in charge, the potential problems with product liability, and last but not least, the absence of a noticeable demand.

3.2.5. *Dutch authorities opinion about ISA*

Goldenbeld (2004) studied acceptance of ISA among Dutch members of parliament. Members of seven of the nine Dutch political parties were interviewed on their policy orientation towards the use of ISA. All politicians were informed about the operation and possible effects of ISA by a special 4-page document which was based on knowledge from international research such as the ADVISORS project. Although all interviewed politicians recognized the safety potential of ISA, most of them indicated having clear reservations towards the obligatory introduction of ISA. These reservations centred around the loss of freedom of choice by the drivers, possibility of fraud and possible unreliability of the system. It was concluded that further knowledge about costs and benefits of specific ISA variants and concrete plans for ISA introduction in the Netherlands would be important incentives for further political discussion about this subject.

So far, there is no central manager in the Netherlands who plays a dominant role in the implementation of ISA on the national level. On the one hand, there is a lot of interest from local and provincial public authorities in ISA, which for example results in ongoing pilots such as in the province of Noord-Brabant (Persbericht Noord-Brabant, 2007). These authorities, however, lack resources to stimulate large scale implementation of ISA. On the other hand, on the international level, there is a tendency towards centralization with policies, standards and requirements for vehicles being set in Brussels or Geneva. This tends to slow down initiatives because it makes sense to implement only after there is legal certainty about standards and requirements. Another negative factor is simply the lack of a "business case" for ISA.

There have been some critical notes about the term ISA itself. Changing 'adaptation' into 'assistance' was considered a good move, but information about (especially static) speed limits is not perceived as intelligent assistance. When the actual choice of speed limits appears not 'credible', 'dynamic' or 'intelligent', the ISA system cannot overcome this handicap.

Although some civil servants in the Dutch government were quite positive about the implementation of some type of ISA on a personal basis, there was no large scale project or budget to speed up development of ISA. Investments are made by the Dutch government, however, to create a digital speed map of the Dutch road network (www.maximumsnelheid.info), catching up with Scandinavian countries that have made good progress with their maps in recent years.

Despite the more observing than proactive attitude of the Dutch government, they continue to explore further steps in the deployment of ISA. Recently a study of marketing strategies has been performed, investigating possibilities to stimulate an accelerated introduction of ISA in the Netherlands. To make short term deployment more successful, it was suggested that open or half-open ISA could be introduced in the market as a product that reduces the risk of speed fines (Bal et al., 2006).

3.3. Stakeholder preferences

This section will summarize the existing literature on stakeholder preferences regarding ISA. These preferences can be defined as stakeholders' valuation of outcomes of interest of ISA implementation. *Section 3.3.1* summarizes what these outcomes of interest are, and *Section 3.3.2* discusses the existing knowledge on which values stakeholders attach to the outcomes. Research on stakeholder preferences for ISA operational characteristics is discussed in *Section 3.3.3*.

3.3.1. *Outcomes of interest for ISA stakeholders*

Outcomes of interest (or criteria) are those outcomes or effects of ADAS that are related to the goals and objectives of stakeholders involved in ADAS implementation (see *Appendix*). These can be considered as the criteria upon which stakeholders base their evaluation of ADAS implementation.

Stakeholders may have different outcomes of interest. Within the ADVISORS project (ADVISORS, 2002) the following criteria to evaluate ADAS were identified:
- society: network efficiency, public expenditure, third party safety, environment and socio-political acceptance;
- users: driver comfort, full user cost, driver safety and travel time;
- industry: acceptance risk and technical feasibility.

Walta et al. (2005) identified stakeholder driving forces and barriers for implementation of co-operative road-vehicle systems (a subgroup of ADAS, see e.g. *Section 2.3.5*). These give an indication of the outcomes of interest. The following objectives were found to be a driving force by Walta et al. (2005):
- authorities: safety, throughput and cost savings;
- user: efficiency (professional users), comfort (private users), safety and image;
- industry: competitive advantage, regulation, comfort and safety.

Regulation may seem a strange objective, but this is related to the fact that obligation of a certain system means a guaranteed market for a product.

The requirements for implementation of co-operative road-vehicle systems that were found are:
- user: cost, privacy and clear benefits (all to be satisfied at a certain level);
- industry: profit;
- in general: co-operation among stakeholders and market penetration of the system.

These two studies show that differences are present among stakeholders, as far as their most important outcomes of interest are concerned. And, while some outcomes of interest seem to be similar, such as safety, there still are differences in perspective. For example, the authorities are interested in third party safety, which means safety for all road users, but users are interested in (individual) driver safety. Furthermore, the industry is probably interested in safety because of product liability and because the user is interested in safety: they can sell safety systems which means profit to them (under the condition of low liability risks due to product failure). As a result, the effects of a certain ADAS implementation strategy do not necessarily have positive implications for both driver and third party safety. Or in other words: the perception of the effects on safety plays an important role.

3.3.2. *Stakeholder valuation of outcomes of interest*

This section gives an overview of the valuation of outcomes of interest (or preferences) for Intelligent Transportation Systems (ITS) in general. The focus here has been broadened to ITS systems because information on stakeholder valuation of outcomes of interest with respect to only ISA is too limited.

Research on valuation of outcomes of interest is generally included in research on decision-making. Decision making, as considered here, can be characterized as prioritizing *alternative courses of action* (further: alternatives). Stakeholders compare these alternatives on *criteria* (i.e. outcomes of interest) that are related to their own *objectives* and the *attributes* (or characteristics) of an alternative. The performance of the alternatives on the criteria is evaluated by *outcome indicators* that produce estimates of the outcomes of interest, called *outcomes*. In case the outcomes cannot be measured objectively or information on the effects is unavailable to the stakeholder, they base their decision on *perceived outcomes*.

The *valuation of outcomes of interest* consists of two consecutive steps. The first step includes the definition of which values of an outcome are positive or negative for a stakeholder. For example: a high level of safety is preferred to a low level of safety and low costs are preferred to high costs. This can be described by an *outcome value function* (see e.g. Beroggi (1998)). The second step involves the comparative *weights* stakeholders attach to the various outcomes of interest, showing the relative importance of these outcomes for the stakeholder.

The prioritization of alternatives is based on an (implicit) *decision rule*, based upon the criteria, effects, weights and value functions. This decision rule can be represented by a mathematical function, which is usually additive but can contain multiplicative terms as well.

The overview in this section presents result from three studies on valuation of outcomes of interest. Although these studies used different approaches, the results of these studies can be compared reasonably well. State of the art methodologies were applied in each of these studies.

Lathrop & Chen (1997)
Two focus group sessions were organized in order to elicit stakeholder preferences for Automated Highway Systems. Several representatives of crucial stakeholders participated in this study with whom they built lists of Performance Impact Measures (PIMs), which are comparable to outcomes of interest, for the user/non-user, the government and the vehicle industry. For the PIMs scales with endpoints (worst and best performance) were determined. The members of the focus group ranked the PIMs for the stakeholder groups they represented in order of importance. These rankings were used to define the weights of the PIMs for each stakeholder group. This approach resulted in quite detailed information on stakeholder preferences.
The top 5 rankings are displayed in *Table 3.2*. Safety appears in the top 5 lists both for the government (authorities) and the user, but different impact measurement scales for safety are adopted for both stakeholders: the number of accidents for users and non-users and spin-off benefits for the government.

ADVISORS (2002)
The ADVISORS study applied a Multi Criteria Analysis (MCA) to rank alternative implementation options for ADAS. Criteria weights were elicited from expert opinions, using the Analytic Hierarchy Process (Saaty, 1980). All criteria were assessed in one survey using pair wise comparisons, from which the relative weights for the different stakeholders were retrieved by setting the non-relevant criteria for that stakeholder to zero. The rank order of all criteria included in the investigation is displayed in *Table 3.2*.

Marchau et al. (2002)
In this study a stakeholder analysis on ISA was performed, using Multi Attribute Assessment. Many different aspects, that are considered to influence the first implementation phase of ISA, were assessed. While for some aspects, information is provided on the differences between stakeholders, the main results of this study averaged over all stakeholders participating in it. The assessment of desirability of ISA for general transportation goals included in this study is comparable to the valuation of outcomes of interest, and is therefore also displayed in *Table 3.2*.

Source	Systems	Authorities	User	Industry
Lathrop & Chen (1997)	AHS	Safety Capital cost Incrementability Infrastructure Institutional attractiveness	Safety Travel time savings Flexibility System integrity Travel time predictability	Liability Customer objectives Marketability Image Incrementability
ADVISORS (2002)	ADAS	Third party safety Environment Network efficiency Acceptance Public expenditures	Driver safety Travel time Full user cost Driver comfort	Technical feasibility Acceptance
Marchau et al. (2002)	ISA	Reduction of accidents Less penalties for speeding Increased driving convenience General desirability Less fuel consumption/environmental load Increased road capacity		

Table 3.2*. Valuation of outcomes of interest.*

In these three studies, safety or accident reduction was ranked most important in all cases, except for the industry. Especially for the user, safety outweighed other outcomes by far. The same kind of results were found by Levine & Underwood (1996), who investigated the valuation of goals of an ITS system integrating adaptive traffic controls and real time route guidance. The primary goals of the system were travel time reduction and safety, of which safety (collision reduction) turned out to be by far preferred above any other outcomes. However, safety is not present in the top 5 of the industry. Industry might view safety as a secondary goal, supporting primary goals such as customer objectives and marketability.

3.3.3. *Operational characteristics of ISA*

Stakeholder preferences with respect to ISA have been investigated for different characteristics of the system, including level of driver support (i.e. information versus control), type of legal speed limit (i.e. static versus dynamic speed limits) and policies (i.e. voluntary versus mandatory implementation). These three aspects will be discussed below, summarizing relevant literature.

3.3.3.1. Level of driver support

Three of the four levels of driver support according to *Table 2.2* are referred to in this section: warning, intervening and automatic control (here called: limiting). *Table 3.3* presents the varying stakeholder preferences regarding the levels of ISA support. The first column presents the studies included in this overview. The second column presents the evaluated ISA options, allowing the results to be viewed in the correct perspective. Several studies averaged over the three main (or more) stakeholders.

The general conclusion that could be drawn from *Table 3.3* is that warning is the most preferred driver support type by users and for private cars, and intervening and limiting types may be preferred in specific situations and for specific driver types.

The results from the ADVISORS study (ADVISORS, 2002) strongly deviate from the average results in *Table 3.3*. This might be related to the fact that in this study, a multi-criteria analysis was applied, while in the other studies subjects had to choose from several ISA types. Multi-criteria analysis primarily is a decision aid, enabling the evaluation of alternative solutions on multiple criteria that reflect stakeholder goals and objectives. The deviation of the results could mean that either stakeholders decide based on other objectives than assumed in the study, or that the estimated effects of ISA included in the multi-criteria analysis differ from the effects that stakeholders perceive.

There is not enough information available on authorities and industry to draw straightforward conclusions on their ISA preferences. However, for the automotive industry it is known that a limiting ISA, that cannot be overridden, is not only their least preferred option, but it is strongly opposed by them (Reinhardt, 2004). Averaging the preferences of different stakeholders (e.g. PROSPER, 2004) may become meaningless for policymaking if a powerful stakeholder like the automotive industry turns out to be reluctant towards certain developments. Consequently, the results of studies that average stakeholder opinions may be useful to determine feasible directions of development, but are not specific enough for policy decisions.

The point mentioned above that different ISA types may be preferred for different target groups has been recognized by several other studies. However, these did not focus on the desirability of the level of driver support for that group, but on the acceptance of a certain level of ISA intervention. For example, it was suggested by several stakeholders and experts that the private users will probably accept intervening systems, and commercial transportation may accept limiting systems (Walta et al., 2005). In the Dutch ISA trial it was found that bus drivers were more positive about the limiting ISA system than car drivers. Furthermore, it appeared that female and elderly drivers were almost indifferent between warning and limiting ISA (Cuypers, 2004), and more willing to purchase ISA than drivers in general (Piao et al., 2004).

Marchau et al. (2005) show that in general willingness to pay for ISA depends on the functionality, being positive for a functionality that combines limiting ISA in neighborhoods with warning or intervening ISA on rural roads and motorways.

Finally, not all studies take the intervening ISA type into consideration, leaving the subjects to choose between two alternatives with major differences – warning and limiting. Some positive opinions on the intervening ISA type can be recognized (e.g. Várhelyi & Mäkinen, 2001), which make it promising enough to be kept in consideration, as well as limiting ISA for specific situations or target groups (e.g. Marchau et al., 2005).

<table>
<tr><th>Source</th><th>Method</th><th colspan="2">Evaluated options</th><th>Authorities</th><th>User</th><th>Industry</th></tr>
<tr><td>Marchau et al. (2001)
Journal paper</td><td>Survey</td><td colspan="2">– None
– Warning
– Limiting</td><td></td><td>Warning</td><td></td></tr>
<tr><td>Várhelyi & Mäkinen (2001)
Journal paper</td><td>Survey</td><td colspan="2">– Intervening
– Limiting
– Neither of both</td><td></td><td>Intervening</td><td></td></tr>
<tr><td>Cuypers (2004)
Presentation</td><td>Survey</td><td colspan="2">– Warning
– Limiting</td><td></td><td>Warning
If warning -> main roads/motorways
If limiting -> residential areas</td><td></td></tr>
<tr><td>Piao et al. (2004)
Conference paper</td><td>Survey</td><td colspan="2">– Warning
– Intervening
– Limiting</td><td></td><td>Warning</td><td></td></tr>
<tr><td>Marchau et al. (2005)
Journal paper</td><td>Survey</td><td>– Warning
– Limiting</td><td>Neighborhood, City, Rural, Motorways</td><td></td><td>Warning (rural, motorways)
Limiting (neighborhood, city)</td><td></td></tr>
<tr><td>Reinhardt (2004)
Presentation</td><td>.</td><td colspan="2">(point of view)</td><td></td><td></td><td>Warning, Intervening (if switch-off possible)
Limiting is out of the question</td></tr>
<tr><td rowspan="2">ADVISORS (2002)
Report</td><td rowspan="2">Multi Criteria Analysis (AHP)</td><td rowspan="2">– Warning
– Intervening
– Limiting</td><td rowspan="2">Rural, Urban
Static, Dynamic</td><td>Limiting</td><td>Intervening (Urban)</td><td>Intervening (Rural)</td></tr>
<tr><td colspan="3">1 Limiting
2 Intervening (Urban)
3 Warning (Dynamic)</td></tr>
<tr><td>Marchau et al. (2002)
Report</td><td>Multi Attribute Analysis</td><td colspan="2">– Warning
– Limiting</td><td colspan="3">Warning</td></tr>
<tr><td>PROSPER (2004)
Report</td><td>Policy Delphi</td><td colspan="2">– Warning
– Intervening
– Limiting</td><td colspan="3">Intervening (professional, novice drivers)
Limiting (speed offenders)
Intervening (freight transport, buses, motorcycles)
Warning (private cars)</td></tr>
</table>

Table 3.3. *Stakeholder preferences for intervention type*

3.3.3.2. Voluntary versus mandatory

An important policy item dealing with the operational characteristics of ISA is the distinction between voluntary and mandatory use of ISA. In case of voluntary use drivers can decide themselves if they want the system in their car, while mandatory implementation forces everyone in a user group to implement the system. Although there are other feasible policy options, like incentives, these have not been considered in the sources included in this investigation.

The number of sources that discuss ISA policies is quite limited, but the results point in the direction of voluntary implementation being preferred (Marchau et al., 2002; PROSPER, 2004; Reinhardt, 2004). However, when future scenarios instead of only the policies were compared, stakeholders preferred a scenario comprising mandatory implementation of assisting ISA for all cars on all roads. This could reveal that, if stakeholders are confronted with the benefits of more intervening systems and mandatory implementation, they might eventually prefer these. It is possible that at first sight stakeholders dislike a system type, but if they are to (rationally) value them on their effects they would choose that type after all. However, taking into account the vision of the automotive industry (Reinhardt, 2004) and the fact that they were not explicitly represented in the PROSPER study, it is questionable if this result reflects stakeholder consensus.

Finally, the preferences regarding voluntary or mandatory ISA use seem to be related to the preferences regarding the level of driver support. Both voluntary implementation and warning ISA leave most freedom to the driver (warning); whereas both mandatory implementation and limiting ISA put stronger limits to this freedom.

3.3.3.3. Speed limit type

All three speed limit types (static, variable and dynamic), defined in *Section 2.2*, were considered in the present studies. In the ADVISORS (2002) study, the most preferred ISA scenarios by all stakeholders included dynamic speed limits (be it for different road types for each stakeholder group). The same general preference for dynamic speed limits was found by Marchau et al. (2002) and PROSPER (2004), but the latter study also shows some differences for specific roads: static is preferred for low-speed, residential areas and variable for major roads outside the built up area. While no explanation was given for these differences, the reason for preferring static speed limits in residential areas could be that a more sophisticated speed limit type is not necessary, and for variable limits on major roads outside the built up area dynamic speed limits are not thought to be feasible from a technical point of view. This explanation coincides with a stakeholder comment that dynamic speed limits are most desirable but less feasible and that the system should not take too much responsibility from the drivers (PROSPER, 2004). There were no major differences found among stakeholders, or it should be that industry did not show a preference for a specific type of road or speed limit (Marchau et al., 2002). This might be because there is no major difference in the in-vehicle units, at least not in the way the system interferes with the driving task.

3.4. Conclusions

This section summarizes the overall conclusions of the positions of three main groups of stakeholders (consumers/road users, public authorities, and industry) regarding ISA. A distinction has been made between acceptance and preferences. With respect to these two items the present literature pays most attention to the consumers/road users group. However, for the other two groups some general stances could be described.

Theoretical perspectives on the acceptance of new innovations or policies identified several factors that are important for increasing the acceptance and use of ISA. The following factors were found to increase or decrease the acceptance by road users.

The acceptance of ISA by road users will be higher if:
- the driver support level is informing or warning;
- there is an influential early adopter group that will serve as example to others and will spread a positive message to others;
- the chance of avoiding speed tickets is increased (or if it is associated with the chance of avoiding speed tickets);
- the chance of avoiding traffic accidents is increased;
- the system increases fuel savings;
- the purchase costs are reasonably low: e.g. considerably below € 300;
- the system is seen as a continuation of a credible system of speed limits that links different road layout and traffic situations to different limits;
- there is a focus on advantages of the use of ISA within urban areas.

The acceptance of ISA by road users will be lower if the system:
- is associated with a mandatory system without any override possibility;
- is mainly thought of as a sanction method for repeated speed offenders;
- is mainly thought of as a help system for less competent drivers;
- needs to operate with speed limits that are not credible.

The following main observations are made regarding stakeholder preferences:
- Most of the effort in the assessment of individual ADAS stakeholder preferences concentrated on the user;
- The three main stakeholders (authorities, users and industry) are found to have a different valuation of outcomes of interest. Authorities and users value safety highest, while for the industry factors that relate to financial risk are most important. The expectation of industry that ISA will be introduced later and cost more compared to other stakeholders' expectations, underlines this specific position of the industry;
- Freedom of driving seems to be an important issue in valuation of alternatives. Willingness to pay for ISA seems positive for 'a functionality that leaves sufficient individual freedom for the driver in a considerable part of the network'.

Based on the insights of acceptance and preferences of the different stakeholder groups, *Table 3.4.* presents an overview of ISA stakeholder positions.

Type of ISA	Public acceptance related to different conditions			Preference among different actors		
	Market introduction (Voluntary)	Restricted measure (e.g. only 30 and 50 kph roads inside urban areas)	General measure (throughout Europe)	Authorities	Users	Industry
Warning	+++	+/-	NA	+++	++	+
Intervening	+++	+/-	NA	+	+	+/-
Limiting	?	+	+	+	+/-	-

NA Likely no studies available
- almost no support; strong resistance
+/- ambivalent feelings that may swing either way
+ overall positive support (but with possibility of strong resistance)
++ clear majority support (still with possibility of strong minority resistance)
+++ strong majority support (no resistance)

Table 3.4*. Overview of stakeholder positions.*

The table shows that voluntary warning ISA is accepted and preferred most among the stakeholders. Furthermore, the table gives a somewhat contradictory picture of the mandatory introduction of ISA. The most promising ISA type in terms of expected safety effects, i.e. a mandatory limiting form of ISA, is the overall least preferred form. However, it does not follow that mandatory introduction lacks substantial public support, as has been shown by a major survey among European car drivers in 2002.

Not only safety plays a role in stakeholder decision behaviour. For the *industry*, costs and financial risk are important considerations. *Road authorities* are reluctant to take a strong position on the introduction of ISA if the system is not (yet) proven fail safe on a very high reliability level. Besides, national politicians (at least in the Netherlands and Germany) take a reserved stance towards introduction of ISA, partly caused by the heavy association of ISA with mandatory, closed systems of speed control. Furthermore, there is a lack of strong management on the national and international level in Europe to speed up ISA developments. For *road users* experiences or implied threat to individual freedom are important.

The name ISA may in itself be one of the obstacles to a larger scale implementation of speed assistance systems in vehicles, since it evokes associations with loss of speed control for individual drivers and with intelligent advice that may not be met. Therefore, the term SpeedAlert has been introduced for informing and warning ISA types to stress the central importance of the individual freedom of the driver, leaving full control of driving speed to the driver.

It should be noted that it is difficult to compare results from different surveys as the description of the speed support system differs, the exact survey question and answer differ, and the survey samples differ. Likewise, the preferences of different actors depend upon the method used. Preferences based on multi-criteria analyses differed from preferences based on stated choice/preference assessments of alternatives. This could be caused by the influence of perceived outcomes on the judgment of stakeholders or the omission of important criteria.

Nevertheless, the present evidence from various sources fairly supports the following conclusions:

- Market introduction of new speed support systems that allow drivers free control over their own driving speed will be received favourably by drivers/consumers.
- Limiting systems receive both active resistance and positive support throughout Europe. In general, resistance comes up when personal freedom is at stake. Considerable support however comes up, when drivers are thinking about effective measures, particularly if it would be restricted to 30 or 50 km roads inside urban areas and financial consequences are not too large.
- Decision-making on ISA implementation is slowed down by the differences between stakeholder preferences. There seems to be enough consent to implement warning systems, but the lower effectiveness with respect to safety compared with limiting systems, makes its contribution to a solution for transportation problems somewhat more questionable.

Whereas a mandatory introduction of ISA is not the most likeable option to all stakeholders, authorities and drivers may realize it could be the single best, effective measure to cope with the collective nature of the speeding problem and its' negative costs in terms of safety, environment and well-being. It is also conceivable that public support for a mandatory introduction for ISA would be quite substantial if the focus of mandatory use were to be on dangerous roads inside urban areas. A measure that would be stringent as to speeding in urban areas and lenient in areas outside urban areas, might well appeal to the conflicting thoughts and emotions persons tend to have when they think about driving and speeding.

As closing notes for this chapter, the following questions reflect the areas of interest for further research on stakeholder positions:

- How should stakeholder preferences be assessed in order to reflect their actual position towards policy or market introduction alternatives?
- How can the change of preferences over time be included in the investigation?
- Should a further distinction be made within the main stakeholder groups, i.e. are there major differences in stakeholder preferences within the main stakeholder groups?
- How can the general priority alternative be deduced from different stakeholder positions, for example, how should stakeholder influence be accounted for?

4. Implementation strategies for ISA

4.1. Introduction

A promising perspective and more insight in stakeholder positions are important conditions for starting and guiding the implementation of in-vehicle speed support systems. Besides, the way in which the implementation process is organised, will strongly influence its success. This chapter describes relevant aspects of implementation strategies for ISA, to get more insight into the implementation process.

The previous chapters have shown that the implementation process is subjected to a complex environment. Different objectives need to be aimed at, there should be a good integration with traditional measures, and there are many stakeholders from different sectors having important positions and playing important roles, that are not sufficiently clear yet. Furthermore, functionalities and technologies of the in-vehicle applications should be attuned to other in-vehicle systems and to other components of the traffic system, e.g. in the infrastructure, or for enforcement, service providers, insurance companies etc. Implementation in such a complex environment introduces uncertainties, that demand a strategic implementation approach. Such an approach should facilitate the formulation of expectations of in-vehicle speed support systems for the short and long term.

Considerations that should be made in a very early stage of such a strategic approach deal e.g. with *coordination of the implementation process* and *cooperation between government parties and market-orientated parties*. In general, public authorities appear to be in the best position to lead the coordination process. In most countries, they have the responsibility for the quality of the overall traffic and transport system, and they have the overview of what is available in the market and how various applications and measures can interact (e.g. new/traditional, explicitly aiming at safety/or not). For instance the information that is provided in the vehicle should seamlessly connect to road design, traffic rules and information on road signs. At the same time the role of the market is important, since there is a strong need to match benefits for society as a whole with those of individual drivers (that are directly served by the market, see e.g. the notes on acceptance and innovation theory in *Section 3.2.2*). Therefore a good balance will be needed between governments parties and market-orientated parties. For ISA and other in-vehicle ITS this is more complicated than for the existing vehicle regulation, that has been established on a European level, with less stakeholders involved.

Section 4.2 gives examples of components of ISA implementation strategies, in case the main initiative is in the market or with government parties. The following sections explore how public policymaking could deal with the complexities and uncertainties surrounding the implementation of ISA. First the point of departure and the theory is described in *Section 4.3* and *4.4*. *Section 4.5* will then place it further in the perspective of ISA.

4.2. Examples of strategy components

This section describes components of two types of strategies. *Mainly market-driven*: public authorities provide boundary conditions, leaving the initiative to the market. *Mainly government-driven*: promising systems are not deployed due to serious market failure or a lack of market initiative. The section starts with some general components that apply to both types of strategies.

4.2.1. *General components*

A good basis for an ISA implementation strategy would be the establishment of a generally accepted framework for an overall ITS policy at international, national and local level. All stakeholders involved should participate in it and it should be aimed at mutual cooperation. To achieve this, a road safety agreement for the implementation of ITS, with special focus on ISA, could for instance be an appropriate form (Wegman & Aarts, 2005). Such an agreement should reduce uncertainties for all stakeholders about the pace and direction of developments.

Following up on this agreement, the implementation of ISA could very well be considered to be part of a wider path for ITS deployment. Herein four successive stages can be distinguished, based on frequently used product development curves in Information and Communication Technology (ICT). These stages range from relatively simple intelligent transport systems, in line with current market developments, to more complex ITS systems that currently are in their infancy (Morsink & Wegman, 2006).

1. *Initiation: exploration of application possibilities.*
2. *Popularization: individual applications.*
   Separate applications, that have part-proven themselves, are increasingly used.
3. *Control: combined applications.*
   Separate applications, that have proven themselves, are linked, thereby achieving a larger effect.
4. *Integration and coordination: coherence by coordination.*
   This is the ultimate goal in terms of:
   - an integral safety system in which ITS has obtained a clear position in relation to other safety interventions;
   - a harmonious safety system in which ITS has obtained a clear position in the overall traffic and transport system (integration of objectives and parties);
   - optimum mutual interconnection of various ITS applications;
   - insight into the effects and coherence of various ITS applications;
   - wide support for investments in ITS developments because the benefits outweigh the costs, and are clear to all parties.

4.2.2. *Mainly market-driven*

These stages can be illustrated by a 'user-demand example', in which it is assumed that consumers are interested in speed support by ISA. This is preceded by joint market and government activities to gain public support through creating awareness. Implementation then mainly takes place through market mechanisms, and the initiative lies with the market. If the market fails, public authorities can supply some momentum, e.g. by subsidies, facilitating research, acting as a partner in demonstration projects, or acting as a role model, such as the Swedish Road Administration is currently doing by equipping their own professional vehicle fleet. Furthermore, governments should provide some *regulation*, e.g. to exclude immature and unsafe products, a *legal framework* to deal with liability issues, and *standardisation* to guarantee that the systems do what they promise. The example is further worked out in *Table 4.1*.

Initiation (2005-2015) The vehicle fleet is increasingly fitted with Cruise Control, Adaptive Cruise Control, manual speed limiters, and navigation systems. Added to this, voluntary, non-intervening ISA is introduced: static speed warning by road type. Information is provided based on a digital map and GNSS positioning, covering the whole road network. Floating car data (position, speed) starts to be used in navigation systems for more accurate and quasi real-time traffic/route information. Awareness and support are increased by equipping professional vehicles, and by supplying target groups such as young and novice drivers with ISA.
Popularization (2008-2018) Static speed warning at locations with increased risk (e.g. near schools), as well as systems that warn for appropriate speed in curves, 'predictive cruise control' and warning for traffic jams and bottlenecks. The driver experiences speed information as normal. Also, systems are available that warn for vulnerable road users and obstacles. Information is gathered based on a digital map and GNSS positioning, autonomous car sensors and vehicle-to-infrastructure communication.
Control (2012-2022) Dynamic speed warnings depending on local conditions. Forms of limited intervention by the system in case of speed offences in selected circumstances based on positive experiences and observed effects from trials. Information is gathered by methods mentioned before and by vehicle-to-vehicle communication.
Integration and coordination (2015-2025) Integral speed control system: safety has been incorporated in harmony with other objectives in the traffic system. Bi-directional information exchange exists between vehicles (drivers) and the infrastructure (car-to-X communication). Car-to-X communication is used to establish dynamic speed limits and to provide real-time route information. The driver receives support when needed. Traffic is optimally organized at local and network level.

Table 4.1. *Example of a mainly market-driven implementation of Intelligent Speed Assistance.*

4.2.3. *Mainly government-driven*

In a contrasting example, it is assumed that road users show no or limited interest in speed support by ISA, although it is expected to yield large scale safety and other benefits. As a result the application is not taken up by the market, and its unpopularity will delay or even stop the implementation, if no additional actions are undertaken. Support needs to be established here, e.g. for high risk groups such as frequent and large offenders, or young inexperienced drivers. When sufficient support has been gained, implementation can be started, if necessary by compulsory measures or other pressure from the government. Pilots such as in Denmark, where insurance companies reduce the premium for young drivers if they install

ISA in their car, show that market forces can already play an important role in an early stage of this process (Schmidt Nielsen & Lahrmann, 2004).
For both implementation types (user demand versus public authority driven), implementation is reinforced by integration with other developments and objectives.

4.2.4. *Other examples*

These examples give an interesting impression of what could eventually be possible with a progressively developing traffic system, in which ISA plays a central role. Other examples that may add to the ones presented here can be found in e.g. Bal et al. (2006), Carsten & Tate (2005) and PROSPER (2005).

There is a range of uncertainties that have to be adequately overcome in order to reach the visionary position outlined above. The following sections describe some of these uncertainties related to current policy making and propose a way to deal with them in the implementation process from a policy making point of view.

4.3. **Experiences from current (proposed) implementation strategies**

Transport policymakers in various countries are becoming increasingly interested in the large-scale implementation of ISA (PROSPER, 2004, 2006). However, there seems to be a considerable gap between what is technologically possible and what has been achieved in practice regarding ISA implementation. Policy development regarding ISA is hindered by large uncertainties about the outcomes of large-scale ISA implementation, and by the valuation of the outcomes by stakeholders involved in or affected by implementation decisions (Marchau, 2000).

Until now, the development of ISA systems has been mainly *technology driven*. The performance and impacts of ISA on a large scale have been *assessed only in experiments* under controlled conditions, implying limited real-world validity. ISA technology development and its impacts are *strongly related to the societal conditions* that have to be fulfilled for implementation, e.g. regarding personal freedom and drivers' own responsibilities. Another issue involves *legal regulations*. It might be necessary to change rules in the context of liability and third-party insurance for intervening and automatically controlling ISA.

These types of issues generate major uncertainties surrounding ISA implementation. Current policymaking is often characterized by a 'wait and see' attitude in response to these uncertainties, allowing developments to be largely determined by market forces. This relatively uninvolved approach could actually slow down ISA development or could lead to the implementation of ISA applications that serve producers’ and individual consumers’ interests only, not more general transport policy goals.

Hence, there is a need for an ISA policy course that recognizes the existence of uncertainties, and that is prepared to act upon them, without neglecting the possibilities and responsibilities of public authorities with respect to general transport policy goals.

In the next sections, such a course is presented by focusing on identifying and handling relevant uncertainties within the context of ISA policymaking. This approach involves a flexible or adaptive policy, which allows adaptations in time, as knowledge about ISA proceeds and critical events for ISA implementation take place.

4.4. Innovative policymaking for ISA[2]

4.4.1. *An integrated view on transport policymaking*

Strategic planning with respect to the implementation of ISA requires focusing on the process of transport policymaking. However, over the years most transport policy analysis has been focused on the transport system itself. In the literature, several views (and related models) of transport systems can be found, differing in the transportation problem the researcher encounters and the aims of the study. 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 views and models on the tensions between transport supply and transport demand. There is very little focus or none at all on the decisions made by individuals and organizations involved in transportation processes.

These different views may be useful but too limited from a public policy perspective. Public policy is concerned with intervening at various points in the transport system in a way that takes into account both the interaction among the physical elements of the transport system and the behavioral mechanisms underlying this interaction. Policy analyses and their related models rarely reflect this perspective. In this chapter, therefore, we specify a view on policymaking in general and apply this to the domain of traffic and transport.

According to this view, policymaking concerns making choices regarding a system in order to change the system outcomes in a desired way (see *Figure 4.1*; Walker, 2000a) . At the heart of this view is the system comprising the policy domain, in our case the transport system. It is important (1) to define its boundaries, and (2) to define its structure (i.e. the elements and relationships among them).

[2] *Sections 4.4* and *4.5* are based on: Marchau & Walker (2003)

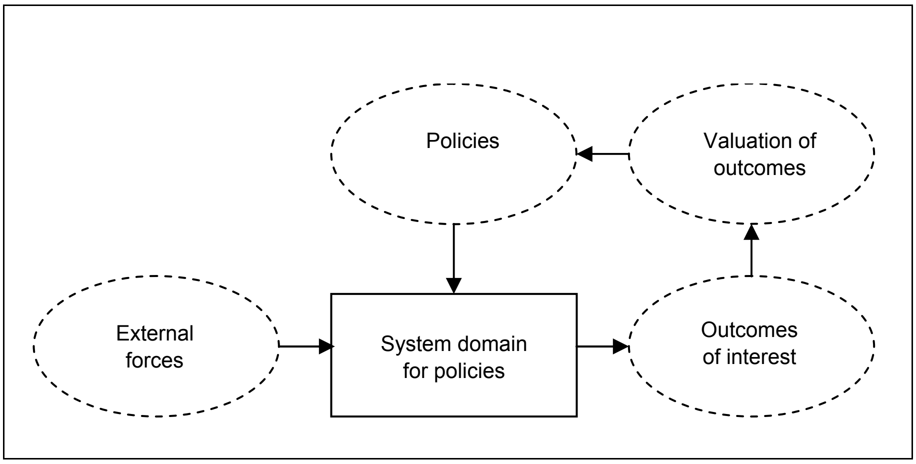

Figure 4.1*. An integrated view of policymaking (Walker, 2000a).*

In general, a transport system can be defined by distinguishing physical components of transportation and their mutual interactions (Van de Riet, 1998). These physical components include the subjects of transportation (people or goods), the means of transportation (vehicles or transport units), and infrastructure. The results of these interactions (the system outputs) are called *outcomes of interest*. Outcomes of interest (see *Section 3.3*) here refer to the characteristics of the system that are considered relevant criteria for the evaluation of policy measures. For transport policies, these criteria involve, for instance, the level of emissions by motor vehicles, the number of road traffic casualties, the amount of noise nuisance, and the level of congestion on the road network (Van der Loop & Mulder, 2003). The *valuation of outcomes* refers to the (relative) importance given to the outcomes by crucial stakeholders, including policymakers (see *Section 3.3.2*).

Two types of forces act on the system: *external forces* and *policies*. Both types of forces are developments outside the system that can affect the structure of the system (and, hence, the outcomes of interest to policymakers and other stakeholders).

External forces refer to forces that are not controllable by the decision maker but may influence the system significantly, i.e. exogenous influences. Well-known external forces on the transport system involve demographic, economic, spatial, social, and technological developments in society. Well-known factors that have affected the daily pattern of vehicle travel include the increase of female participation in the labour force, more flexible office hours and opening hours of shops, and changing land-use patterns (Button & Taylor, 2002; Van Wee, 2002).

Policies are the set of forces within the control of the policymakers related to the system. In other words, a policy is a set of actions taken to control the system, to help solve problems within it or caused by it, or to help obtain benefits from it. In speaking about national policies, the problems and benefits generally relate to broad national goals. For instance, in the Netherlands, the national transport policy goals include the maintenance and improvement of accessibility, increased traffic safety, reduction in harmful emissions and noise pollution, and slowing down the fragmentation of the countryside (Ministry V&W, 2001).

4.4.2. *An integrated view on policymaking for ISA*

Applying this view of policymaking to ISA development and implementation shows the following uncertainties (see Marchau & Walker (2002) for a full discussion).

First, the possible influence of external forces, including ISA technology development, is uncertain. This has been almost completely ignored up until now, although the importance of exogenous events for the development of ISA, like economic developments and demographic developments can be argued. Most ISA implementation studies assume that technological progress will drive the implementation process, neglecting the likely co-evolution of ISA technology and society.

Second, as shown in *Chapter 2*, the outcomes from 'real life' ISA implementation are uncertain. The way ISA implementation might affect transport system performance in practice is not sufficiently known, since the key-relationships determining transport system performance from ISA implementation are uncertain. The current knowledge is restricted to evaluating the intended impacts of specific ISA types, often assuming optimal technological performance of ISA, drivers who do not adapt their behaviour to supportive systems, and optimal traffic conditions. As such, figures on traffic performance improvements by means of ISA implementation are hardly more than indicative.

Finally, as shown in *Chapter 3*, the valuation of the outcomes from ISA implementation is uncertain. Stakeholders tend to have different opinions about the severity of future traffic problems. This results in different, often conflicting, needs regarding ISA implementation. As such, the willingness of stakeholders to accept (or reject) outcomes of ISA implementation is uncertain.

Summarizing, large uncertainties exist about external developments, the outcomes of ISA policy decisions, and the valuation of the outcomes by stakeholders involved in or affected by ISA policy decisions. Up until now, policymakers have dealt with these uncertainties in one of two ways (Walker, 2000b): ignore them, or anticipate on them.

The most common approach is to neglect or ignore them, assuming that the future world will be more or less the same as the current world. While this may be the easiest option for the short term, it means in fact accepting large uncertainty with respect to, for instance, ISA policy outcomes. This could lead to a serious policy failure. *Chapter 2* has identified these uncertainties. For instance, although ISA intends to improve traffic efficiency (or at least not to reduce road capacity), there are studies that forecast some capacity decreases for certain penetration degrees and specific operating characteristics of ACC type of systems that may very well be integrated with ISA. Furthermore, the safety benefits could be outweighed by countervailing behavioral responses by drivers. These negative efficiency and safety impacts may increase in case of a mixed situation of vehicles with different systems, each having its specific type of support and performance.

Implementing an ISA without considering the possible negative impacts could lead to policy failure.

The second approach to dealing with these uncertainties focuses on identifying uncertainties and developing a policy that takes these uncertainties into account. It assumes that the range of future worlds can be specified well enough to determine robust policies that will produce favourable outcomes in most of them. These future worlds are described by means of scenarios. The best policy is the policy that produces the most desired outcomes across different scenarios. Scenarios enable the policymaker to act consciously in the presence of uncertainty. Although this approach has been successful in the past, the problem is that if the range of assumptions about the future turns out to be wrong, the negative consequences might be larger than if the uncertainties were totally ignored.

Traditionally, the construction of scenarios in the field of transportation has been mostly based on trend extrapolations (Banister, 1994). Serious trend breaks are often not included. Events like serious transport accidents and the explosive growth of mobile technology implying substantial changes in activity and mobility patterns are often not taken into account. The question is: In this rapidly changing world, is it feasible to develop and analyze a full set of plausible, future scenarios? It remains difficult, if not impossible, to get sufficient knowledge about the external factors influencing transportation performance. Furthermore, most of (levels of) these factors are inherently unpredictable in the long term (Van Geenhuizen & Thissen, 2002). So, even the degree of uncertainty cannot be estimated.

Hence, traditional approaches have serious shortcomings in handling uncertainties regarding ISA policymaking in an appropriate way. The challenge for ISA policymaking is therefore to develop other, innovative approaches to handle these uncertainties. Instead of only focusing on the identification of all feasible ISA technologies and development paths, an approach is needed that adapts to the future course of events and fully exploits knowledge that becomes available as time proceeds.

4.5. Adaptive policy making: coping with implementation uncertainties

Walker et al. (2001) have developed a so called adaptive approach to policymaking. This approach allows implementation to begin prior to the resolution of all major uncertainties, with the policy being adapted over time based on new knowledge. It is an innovative way to proceed with the implementation of long-term transport policies despite the uncertainties. The approach makes adaptation explicit at the outset of policy formulation. Thus, the inevitable policy changes become part of a larger, recognized process and are not forced to be made repeatedly on an ad-hoc basis. Adaptive policies are devised not to be optimal for a best estimate future, but to be robust across a range of plausible future scenarios. Such policies combine actions that are time urgent with those that make important commitments to shape the future, preserve needed flexibility for the future, and protect the policy from failure.

Under this approach, significant changes in the transport system would be based on a policy analytic effort that first identifies system goals, and then identifies policies designed to achieve those goals, and ways of modifying those policies as conditions change. Within the adaptive policy framework, individual actors would carry out their activities as they would under normal policy conditions. But policymakers, would try to keep the system headed toward the original goals, through monitoring and mid-course corrections.

Figure 4.2 illustrates the adaptive policy process. In particular, the following steps summarize the process for creating and implementing an adaptive policy.

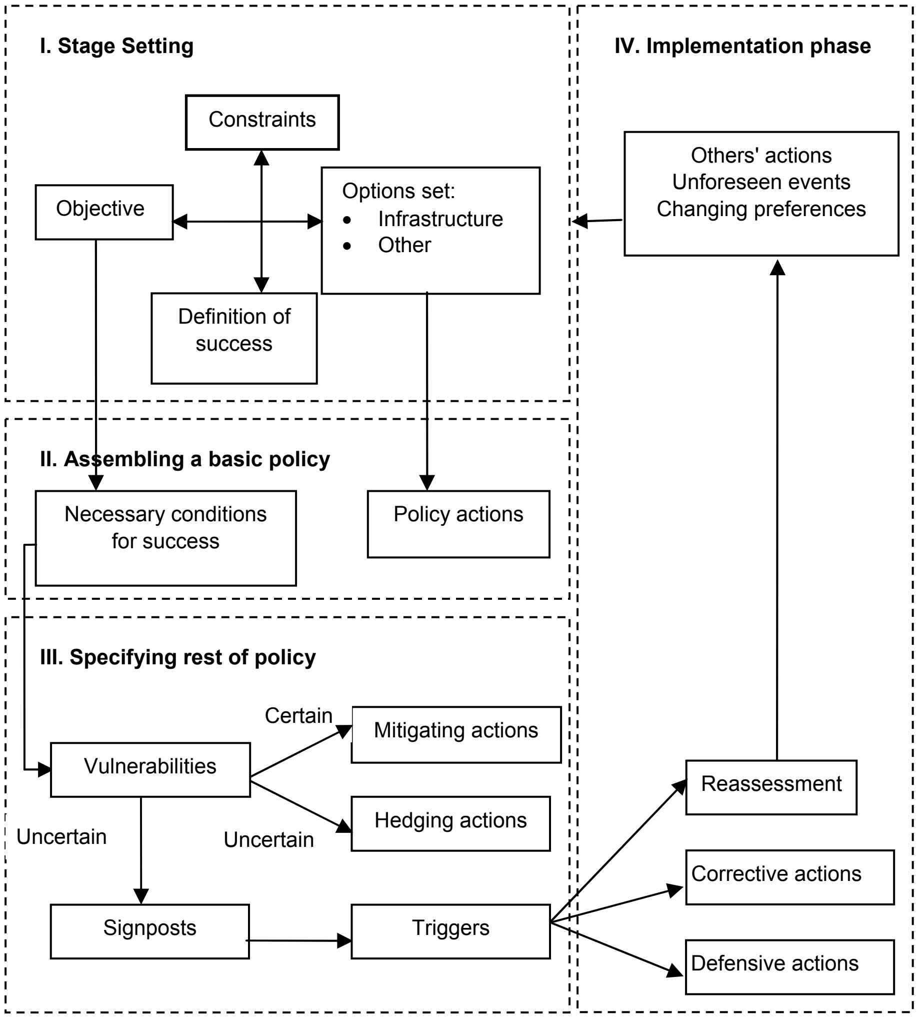

Figure 4.2. *The adaptive policymaking process.*

The first activities constitute the *stage-setting* step. This step involves the specification of objectives, constraints, and available policy options. This specification should lead to a definition of success, i.e. the specification of desirable outcomes.

In the next step, a *basic policy* is assembled, consisting of the selected policy options and additional policy actions, together with an implementation plan. It involves (a) the specification of a promising policy and (b) the identification of the conditions needed for the basic policy to succeed. Note that both the first and the second step are basically the same steps as are currently used in policy formulation.

In the third step of the adaptive policymaking process, the *rest of the policy* is specified. These are the pieces that make the policy adaptive. This step is based on identifying in advance the basic policy vulnerabilities, i.e. the conditions or events that could make the policy fail, and specifying actions to be taken in anticipation or in response to them. This step involves:
a. the identification of the vulnerabilities,
b. defining actions to be taken immediately or in the future, and
c. defining signposts that should be monitored in order to be sure that the underlying analyses remain valid, that implementation is proceeding well, and that any needed policy interventions are taken in a timely and effective manner.

Vulnerabilities can reduce the acceptance of a policy to a point where the policy is no longer successful. Actions are defined related to the type of vulnerability and when the action should be taken. Both certain and uncertain vulnerabilities can be distinguished. Certain vulnerabilities can be anticipated by mitigating actions, i.e. actions taken in advance to reduce certain adverse effects of a policy. Uncertain vulnerabilities are associated with hedging actions, i.e. actions taken in advance to reduce or spread the risk of possible adverse effects of a policy.

In addition, signposts are established for uncertain vulnerabilities to monitor when actions are needed to guarantee the progress and success of the policy. In particular, critical values of signpost variables (triggers) are specified, beyond which actions should be implemented to ensure policy progress in the right direction and proper speed.

Once the above policy is agreed upon, the final step involves *implementation*. In this step, the actions to be taken immediately are implemented, signpost information related to the triggers is collected, and policy actions are started, altered, stopped, or extended. After implementation of the initial actions, the adaptive policymaking process is suspended until a trigger event is reached. As long as the original policy objectives and constraints remain in place, the responses to a trigger event have a defensive or corrective character – that is, they are adjustments to the basic policy that preserve its benefits or meet outside challenges. Under some circumstances, neither defensive nor corrective actions might be sufficient. In that case, the entire policy might have to be reassessed and substantially changed or even abandoned. If so, however, the next policy deliberations would benefit from the previous experiences. The knowledge gathered in the initial adaptive policymaking process on outcomes, objectives, measures, preferences of stakeholders, etc., would be available and would accelerate the new policymaking process.

Table 4.2 gives an overview of the differences between traditional and adaptive policymaking. Although both types of policymaking emphasize the importance of adaptation as a situation unfolds, there are two key differences.

Characteristic	Policymaking approach	
	Adaptive policymaking	**Traditional policymaking**
Consideration of goals	Stakeholders participate in forums to develop and identify the diversity of goals.	Stakeholders pursue their own goals, cooperating at their own initiative
Treatment of uncertainty	Forums explicitly elicit key uncertainties and contingent plans for addressing them	Individual stakeholders ignore uncertainty or address uncertainty based on rigid assumptions.
Potential for system change	Radical system changes may be promoted through cooperative action	Individual preferences enable only incremental system changes
Response to unexpected events	Pre-specification of defensive=corrective actions (if needed), reducing avoidable surprises	Individual stakeholders respond 'ad hoc' to surprises
Monitoring of outcomes	Coordinated monitoring of outcomes as a part of the implementation process.	Limited monitoring, mainly on an ex-post basis.

Table 4.2*. Differences between traditional policymaking and adaptive policymaking.*

First, there is the presence or absence of a common goal among stakeholders. Adaptive policymaking sees this as instrumental, whereas traditional policymaking views it as potentially dysfunctional, since it might slow down decision making.

Second, there is a big difference in the treatment of uncertainties. Adaptive policy analysis is based on identifying in advance the uncertain conditions or events that could make the policy fail (its 'vulnerabilities'), and specifying actions to be taken in anticipation or in response to them. Hence, the adaptive policy allows pre-specified and pre-agreed adaptations in time as knowledge accumulates, learning proceeds, and critical events take place during implementation.

In the following section the concept of adaptive policymaking described above, will be illustrated for developing policies regarding ISA implementation.

4.6. An example of an adaptive ISA policy [3]

This section explores the establishment of an adaptive policy for ISA. It is described in the four steps from *Figure 4.2*, and it is based on insights obtained in the previous chapters.

[3] *Section 4.6* is based on: Mehta et al. (2006)

Step 1 is to identify ISA as an attractive and realistic policy option. *Step 2* deals with the specification of a basic ISA policy to be deployed including conditions for success. *Step 3* is about the identification of vulnerabilities in the proposed policy and signposts/triggers to monitor these vulnerabilities. *Step 4* is the implementation phase where information from the signposts is processed and translated into defensive or corrective actions, if applicable.

4.6.1. *Step 1: Identification of ISA as a policy option*

Step 1 in the adaptive policymaking approach includes the identification of an objective, constraints, and available policy options. The overall safety objective, identified by the Dutch Ministry of Transport, Public Works and Water Management, was a reduction by 25% in fatalities and 22% in serious injuries due to road accidents by 2010 (as compared to the figures of 2003). Furthermore, objectives have been defined for the reduction of congestion, the increase of the reliability of the traffic system, and reduction of pollution (VenW, 2005).

Considering the relationships between speed and the policy objectives, and considering the large number of speed offences in the Netherlands, ISA has been identified as a policy option. Based on the effect estimated, such as described in *Chapter 2*, ISA is set as a policy option that would help to achieve the safety objective, while having a good perspective to contribute to the other objectives as well. The constraints are the limits to the policy. The major constraints would be financial and social. In case the safety objective is most prominent, other constraints are that congestion, travel time, and local pollution should (at least) not increase because of the implementation of ISA.

4.6.2. *Step 2: Specification of a basic ISA policy*

In Step 2, a promising, basic ISA policy is specified and the necessary conditions for its success are identified. A logical, promising policy to start with is to implement a suitable type of ISA for unsafe roads, unsafe vehicles, unsafe traffic conditions, and unsafe drivers.

The basic ISA policy specified for implementation is dynamic, warning ISA on urban roads for young car drivers on a voluntary basis, as explained below.

Urban roads are selected, since they have a higher percentage of accidents than rural roads and motorways (AVV, 2004b). Furthermore, test results show that ISA can be particularly effective and accepted on urban roads. *Passenger cars* are selected since car occupants are the largest group among all traffic casualties, although the overall safety risk of car occupants is relatively low compared with other modes. In turn, *young car drivers* (18-24 year) have a high risk compared with other drivers. *Warning ISA* is selected based on the positions of different stakeholders. Next, because of time-varying traffic conditions, such as incidents and weather changes, *dynamic ISA* is proposed. The communication of the speed limits to the vehicle will be by GPS with built in digital map with speed limits; at places where there is lack of GPS signal, beacons might be installed.

The *necessary conditions* are the ones that will be monitored in the future to ensure the success of the basic policy. One of the conditions of success is that there should be reliable and accurate ISA technology, i.e. reliable communication systems and accurate speed data collection. The most important condition for success is user acceptance. In order to achieve safety objectives, a 60% minimum penetration level of ISA technology is assumed necessary (Carsten et al., 2006).

4.6.3. *Step 3: Identification of vulnerabilities and signposts*

In Step 3 the remaining part of the policy is specified. It is this part that makes the policy adaptive. This step includes two types of analysis:
1. the identification of vulnerabilities, together with the specification of actions to be implemented when the basic policy is implemented, and
2. the translation of the necessary conditions of success and vulnerabilities into signposts.

These signposts will be monitored in the future as implementation proceeds to ensure the smooth implementation of ISA. Any undesired change in the signpost level would trigger a change in policy. Some examples are provided below.

4.6.3.1. Lack of accurate speed limit data

For instance, a certain vulnerability of the new policy might be a *lack of accurate speed limit data.* For instance regarding incidental speed limits (work zones, accidents, etc.) or reliable communication at urban locations where there is lack of GPS signals. A mitigating action in such situations would be to build in some redundancy by providing temporary vehicle-roadside communication around incidents; in the second case, redundancy could be provided by installing communication beacons in built-up areas.

4.6.3.2. Low ISA penetration level

An uncertain vulnerability is a *low penetration level of ISA*, due to low user acceptance among young drivers. Test results show that ISA will have maximum positive effects in terms of accident reduction if the penetration level is 60% to 100% (Carsten et al., 2006). The user acceptance depends on factors like costs, reliable operation of the ISA system, comfort level while driving, etc. If there is low user acceptance, there will be a low level of accident reduction. Hedging actions could be performed in order to attain the required penetration level.

For instance, *promotion and driver education programs* could be undertaken to educate drivers on the potential and the risks of ISA. Another hedging action could be to *provide incentives to the initial users* of the technology, such as by subsidising ISA equipment, lowering insurance premiums, providing free parking for ISA vehicles, lowering taxes for ISA vehicles, etc. Providing incentives would also be a help to young drivers. It should be made clear what incentives should be provided, considering the financial constraints and level of user acceptance and under what circumstances (i.e. now and also in future).

In addition a signpost should be installed which monitors the level of penetration. The trigger value for this signpost involves the minimal ISA penetration level required to achieve the objective. This target value can be changed when required, considering the success attained in the past and what is to be attained in the future. For example, for the signpost penetration level, the desired value might start with an increase of 1% per month with a time limit of 5 years. If at the end of one year an 8% penetration level is attained instead of 12%, a new desired increase in penetration of 1.3% per month might be established for the next 4 years.

Trigger levels for policy actions should be based on target values and regret levels (see *Figure 4.3*). During implementation, if for a signpost the regret level 1 is reached, defensive actions are taken; corrective actions are taken for more critical levels. Also the conditions under which a reassessment of the policy would be made should be identified before beginning to implement the policy. For example, if the number of accidents on the road doesn't change or if they have increased within a stipulated time and the expected outcomes are not being attained or are even getting worse, then the policy has to be reassessed. *Figure 4.3* shows the hypothetical example for the signposts and triggers related to the rate of penetration. A similar figure can be drawn for the other signposts (e.g. change in speed offences and accidents involving ISA users).

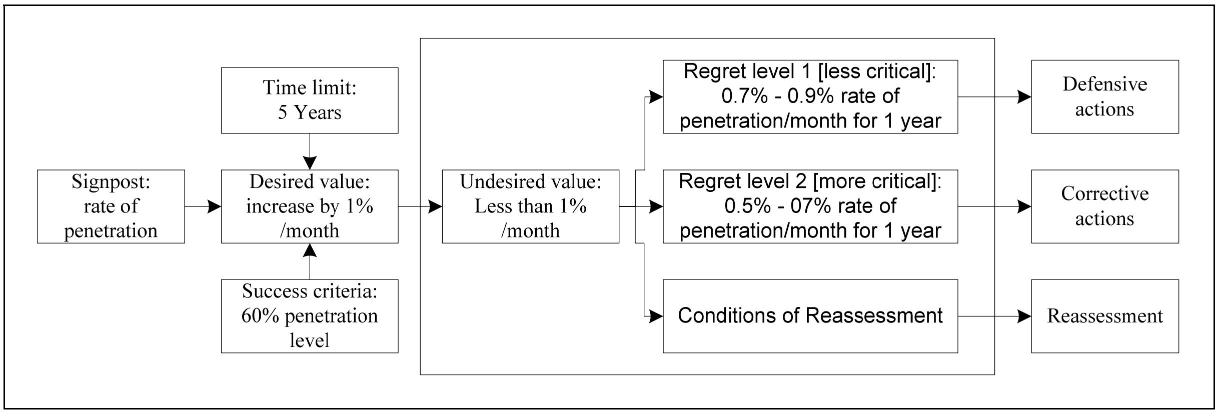

Figure 4.3. *Identifying and handling triggers for the ISA penetration level.*

4.6.3.3. Negative side effects from ISA

Another uncertain vulnerability are negative side effects on driving behaviour, as described in *Section 2.2.5.4*. A hedging action for this vulnerability could be arranging training programs for ISA users and drivers, e.g. using real time simulation for different driving conditions with ISA. This would make the driver accustomed to ISA and its effects before driving on the road. Also, user reports can be developed that would help the ISA implementers to understand the driving problems faced by ISA users. This could also be done by surveying ISA users. The information gained from the users can then be used to develop strategies to improve ISA driving behaviour.

4.6.4. *Step 4: The implementation phase*

Step 4 of the adaptive approach is the implementation phase. During the implementation phase the information is collected for each signpost. The information gathered is compared to the critical level for each signpost. Defensive and corrective policy actions are taken as per the regret level (i.e. level 1 or 2, see *Figure 4.3*). For example, defensive actions to increase the rate of penetration could be investments in R&D to solve the technical operation problems of ISA. Also the user report developed could help to develop defensive actions. For example, if a frequent problem of hardware breakdown is reported, the system can be repaired free or replaced. Also, problems leading to breakdowns can be identified and solved. Other defensive actions could be an increase in speeding fines and installation of speed cameras. If the regret level is more critical, then some corrective actions can be taken, such as implementing ISA on a mandatory basis and increasing the scope of the policy by involving drivers of all ages and for all road categories.

4.7. **Conclusions**

This chapter has explored the implementation of ISA. First, components of implementation strategies have been described, where ISA is part of a wider ITS deployment path. Examples of implementation paths have been shown where market parties and governments have different roles. The demand-driven example in which the market takes the initiative, supported by government parties where needed, provides an interesting perspective. However, it incorporates a lot of assumptions about the future.

Many of the assumptions surrounding ISA implementation relate to the existence of uncertainties related to the future of ISA development and implementation. Public policy and decision making is confronted with those and needs to deal with them. Therefore, the biggest part of the chapter focused on the complexities and uncertainties surrounding the implementation of ISA technology from the perspective of public policymaking. To this end the concept of adaptive policy making has been introduced.

Adaptive policy making allows implementation to begin prior to the resolution of all major uncertainties, with the policy being adapted over time as knowledge about ISA proceeds and critical events for ISA implementation take place. It is an innovative way to proceed with the implementation of long-term transport policies despite the uncertainties. In particular, policymakers are encouraged to first develop a normative view and then guide the implementation and adaptation process based on gathering information that allows the resolution of the uncertainties over time. Herein it should be noted that adaptive policies are devised not to be optimal for a best estimate future scenario, but to be robust across a range of plausible futures scenarios.

The adaptive policy approach was illustrated for a main transport policy objective: an improvement of traffic safety. It has been shown how policymakers can cope with uncertainties in ISA implementation and how these policies might be adjusted as new information becomes available on ISA performance in reality. The perspective of the adaptive approach to handle the range of uncertainties related to ISA implementation is very promising. But the development and implementation of adaptive policies will not be easy; there are significant legal, political, and analytic barriers to be overcome.

Future challenges in this field involve a further specification and testing of the adaptive approach focused on developing systematic approaches to fully identifying the vulnerabilities; the level of (un)certainty of these vulnerabilities and the trigger events and their values. One way of testing of the adaptive approach might be to use scenario and simulation gaming to compare the adaptive policymaking approach to more traditional policymaking approaches.

5. Conclusions

This report has described the possibilities of intelligent vehicle systems for speed support. These systems combine advanced vehicle technology with Information and Communication Technology (ICT), within the wider field of Intelligent Transport Systems (ITS). The report is part of the TRANSUMO Intelligent Vehicles project.

Overall, it has been shown that the role of intelligent vehicle measures in speed management can gradually become more prominent, in combination with traditional measures (infrastructural engineering, education, enforcement). Although potentially large effects are forecast, and technological developments continue, it is still uncertain if and when the systems will find a place among traditional measures, and make their promising perspectives a reality. However, relevant views have been brought together, which can be used to make further steps in research and deployment of the most promising systems. This chapter describes the main conclusions regarding the position of in-vehicle speed support within speed management, the reported effect estimates and deployment effectiveness, with the latter restricted to Intelligent Speed Assistance (ISA).

5.1. In-vehicle speed support within speed management

Speed management aims at optimizing traffic in terms of safety, efficiency and the environment, by reducing speeding and speed differences in traffic. Speed limits are the core of the speed management system, and must be safe, credible and known. Speed limits are preferably dynamic, instead of static, so that they are adjusted to changing traffic circumstances, such as weather, traffic density, pollution levels, and incidents.

First of all, intelligent vehicle measures add to current speed management by helping to deploy this favoured speed limit system. Particularly Intelligent Speed Assistance (ISA) adds to traditional measures by making the driver aware of his own speed and the current speed limit. Whereas the conventional way is to use road signing and road markings, the intelligent vehicle gives the driver direct feedback to on the current limit and on compliance with that limit, at all times and places. As a result, the number of speeding offences is expected to drop considerably. ISA can also lessen the dependency on physical speed reducing measures, such as speed humps. Furthermore, in-vehicle technology can support the driver in choosing the appropriate speed in highly changing, specific conditions, which can not be accounted for in speed limits. Advanced Cruise Control (ACC), and especially the expected next-generation ACC, has such functionality.

Intelligent vehicle systems offer driver support that varies from informing, or warning the driver, to intervention in the driving task and eventually automatic speed control. In this sequence, the freedom of drivers to choose their speed is increasingly restricted. However, as long as drivers can still choose to drive above the speed limit, there will always be a group that will do so, deliberately and regularly. To reach this group, enforcement remains essential. Theoretically, a close to 100% compliance and chance of getting caught could be achieved with intelligent vehicles, if mandatory and intervening systems, or even auto-policing systems (e.g. based on Electronic Vehicle Identification (EVI), and black boxes) are used.

5.2. Effect estimates

Effect estimates have been described for various forms of ISA and ACC, based on a considerable amount of scientific literature. For Vision Enhancement Systems (VES) and black boxes much less suitable literature was available. Direct effects on speed (mean speed and speed variation) and derived effects on safety, the environment and traffic efficiency have been included. Results of different types of studies were used, noting that the evaluation of the systems in real traffic is still rare. Besides difference in the amount of available literature, there are also differences in the sizes and types of effects found in different studies. Therefore only indications can be given of what may eventually be achieved.

For ISA very promising effects are predicted, especially regarding safety. Substantial reductions of mean speed and speed variations were found in almost all ISA studies. Although all types of ISA (informing, warning, intervening, automatic control: static and dynamic limits) have considerable effects, there is a large variation. Informing systems have a much smaller effect than mandatory automatic control systems. Static and variable speed limits have a smaller effect than dynamic speed limits. The most favourable effects are expected from the dynamic mandatory automatic controlling ISA, which could reduce fatal crashes over the entire road network by more than 50%, whereas static informing ISA could still give a reduction of almost 20%. There are also relevant indications of a reduction in fuel consumption and harmful emissions (reductions between 4 and 11% have been reported for CO_2, NO_X, and HC), and of increased traffic efficiency, although research on this topic is still limited.

These estimates assume 100% equipment rates, and the consulted studies did not consistently take possible side effects into account. The following types of behavioural adaptation that may reduce the effects of ISA have been identified: risk compensation may lead to closer following; reduced attention may lead to slower reactions; overconfidence may lead to insufficiently observing traffic circumstances; speed limitation may invoke frustration in the driver himself and frustration in following non-equipped traffic (possibly causing dangerous overtaking and merging), as well as high speed differences between equipped and non-equipped vehicles.

ACC has little effect on the mean speed, but most studies do show a significant decrease of speed variations. This gives strong indications for positive effects on the environment (decrease of fuel consumption and emissions by respectively 3% and more than 10% were reported) than on safety and traffic efficiency. Most beneficial effects of ACC on road safety are expected on motorways, in non-congested traffic, in good weather, and with a 100% equipment rate. For this situation, maximum accident reductions of more than 10% have been reported. For the entire network the effects are smaller. Usage of ACC on different road types and the possibility of adverse adaptation behaviour, for example with regard to overtaking, need to be further assessed. These items, as well as time headway settings and merging behaviour, are also relevant for traffic efficiency impact. More positive effects are predicted for the next generation ACC, which is more designed to detect hazards, and to operate in congestion prone traffic. A combination of ISA and ACC may also be a good option. Where ISA reduces the mean speed and speeding, ACC may add to the system by reducing tailgaiting and reducing speed variations.

The effect estimate for black boxes had to be restricted to a mostly qualitative observation that speeding would considerably decrease, which would have positive effects on all policy areas. VES has been treated as an example of Advanced Driver Assistance Systems (ADAS) which are not directly aimed at speed support, but which have some reported effects on speed behaviour. The improved visibility offered by the system results in an increase of mean speed in low visibility conditions. It should be further investigated what this means for the change of risk.

5.3. Deployment effectiveness

The deployment of ISA has been identified as a multifaceted challenge. It involves many different aspects, such as technological, functional and institutional issues, product image, business models, process coordination and balance between stakeholders.

Effective deployment of ISA requires that the main stakeholders cooperate in a good balance, within potentially successful implementation strategies. There are three main groups of stakeholders for ISA deployment: drivers/consumers, public authorities, and industry. ISA is a challenging case, since its estimated effects on transport policy goals are very promising, but there is only limited market activity as yet (e.g. less than for ACC), and stakeholder positions are not yet clearly tuned to one another..

Stakeholder positions
Studies into stakeholder positions regarding ISA show a general favour of those system alternatives or policies that leave most freedom to the driver. Evidently, there is a trade-off between the effectiveness and acceptance of ISA systems by drivers. However, different results have been obtained depending on the research methodology used to assess stakeholder positions. For instance, guarantees of individual freedom are important for drivers/consumers. Therefore, they are in favour of new speed support systems that will allow them free control of their own driving speed. To stress this aspect the term SpeedAlert is increasingly being used for non-intervening ISA systems, instead of the term ISA which may itself have some negative associations in this respect. But when thinking about effective measures, drivers/consumers prefer limiting systems to purely advisory systems, especially when applied to 30 or 50 km roads inside urban areas, without too large financial consequences, and with fewer restrictive infrastructural measures, such as speed humps. Since ISA is a support system for the system of speed limits, the credibility of both the speed limits themselves and speed enforcement is important for a positive image of ISA. Furthermore, successful diffusion of ISA amongst a larger public necessitates an enthusiastic group of early adopters that have positive experiences and inspire others.

Although ISA is mostly associated with traffic safety, other factors than road safety play a role in stakeholder decision behaviour. For the industry, user demand in a profitable market and related costs and financial risks are important considerations. Road authorities are very interested in ISA, but they are also reluctant to take a strong position on the introduction of ISA if the system has not (yet) proven to be fail-safe at a very high reliability level. In general, government parties are in favour of non-intervening voluntary systems, and they are positive towards market initiatives regarding these systems. At the same time, they are positive about exploring intervening systems for specific target groups (e.g. high risk groups).

Combination of Individual and collective benefits
An important aspect in creating a serious user demand for ISA will be to create awareness of the combination of benefits for the individual driver with collective interests for society as a whole. A first incentive to make ISA more attractive to consumers on the short term may simply be avoiding speed fines. In fact, for this purpose first steps have already been made to integrate ISA functionality in navigation systems. Professional fleet owners also show an increasingly interest. This extrinsic motivation may change into an intrinsic motivation if the predicted advantages of the system in terms of safe, economic and comfortable driving prove themselves in practice. Industry and governments could then further join their interests in ISA. In combination with other ITS developments both in the vehicle and the infrastructure (and especially cooperative systems), ISA functionality may on the longer term become an important part of an integrated driver support system. Such a system could help preventing speeding, tailgaiting, lane departure, and could improve anticipation and homogeneity of the traffic flow. At the same time, it may be an important part of an integrated speed and traffic management system, e.g. resulting in more accurate and reliable traffic information for the individual driver, and multi-objective optimization of traffic flows for road authorities. Such a combination of functions in an upgraded vehicle may make it easier to address individual drivers, and bridge the gap between collective and individual interests.

Coordination and implementation
The deployment of ISA lacks coordination, both on the national and international level. Central governments are in a good position to lead the coordination process, due to the large societal interests that are at stake. In most countries, they have the responsibility for the quality of the overall traffic and transport system. Furthermore, they know what is available in the market, how various applications can interact, and how ISA can be tuned to other speed management measures. Besides, ready-to-roll market models are rare, especially for the most effective versions of the system. A good connection should be established with other national governments, the European Commission, and with local governments.

Within a successful implementation strategy, there should be a good balance between market-orientated parties and government parties. The existence of a market demand will have a strong influence on the course of the implementation process, distinguishing between situations where the initiative is mainly in the market, and government-driven scenarios. Informing and warning ISA (based on static speed limits) is already introduced to the market, though still only to a very limited extent, as an additional function of navigation systems. Also, the market is exploring combinations with ACC. Voluntary intervening systems could be a next step. In this case, gradual market-driven ISA implementation is probably the most realistic scenario. As a coordinator, there will be important tasks for governments to support and guide this process of technology entering the market: creating awareness and informing the public about available systems in the market; to take care of regulation and standardisation to exclude inadequate systems from the market, and to guarantee interoperability and quality. First hand government involvement is required in the development of the digital speed map, which should cover the entire road network and meet strict quality requirements. In the meantime, governments need to consider the potentials and the legal consequences of a mandatory form of ISA, for example for specific risk groups like frequent speed violators or inexperienced drivers. For such effective, but not very popular systems, a government should take the initiative in raising support, whereas a market could also develop over time.

Adaptive policymaking
Despite the interesting perspectives, several uncertainties exist in the implementation and policymaking of ISA. There are uncertainties about external developments (e.g. technology development), the outcomes of ISA policy decisions (e.g. do drivers behave like intended?), and the preferences of stakeholders involved in or affected by ISA policy decisions. There are concerns that traditional incremental policy approaches are rather passive in response to these uncertainties, allowing developments to be largely determined by the flow of market forces, risking an imbalanced focus on producers' and individual consumers' interests. Several experts argue that policymaking should be more active and adaptive. An adaptive policymaking approach has been proposed, that allows implementation to begin prior to the resolution of all major uncertainties, with the policy being adapted over time, as knowledge about ISA proceeds and critical events for ISA implementation take place. An example has been shown that starts with a basic policy, of which the concerning uncertainties can be translated into vulnerabilities that can make a policy fail (e.g. lack of accurate speed limit data, low ISA penetration level, or negative side effects from ISA). The next step in setting up an adaptive policy is to install a signpost to frequently monitor the status of the vulnerability, and the progress of the basic policy. If predetermined threshold values for the signpost are exceeded, defensive or corrective actions are performed, or the policy will be reassessed. The perspective for adaptive policy making is promising, but some legal, political and analytic barriers still need to be overcome, before it can be put it into practice.

6. Recommendations

The estimated effects of speed support systems described in the literature raised questions, e.g. about potential side effects that have not well been taken into account, or about deployment rates of the vehicle fleet in the future. As a result, the estimations could vary significantly, which makes the actually achievable effects quite uncertain. Among the wide range of recommendations that could be made, this section focuses on the reliability of effect estimates and better insight in the (wide area of) processes that may lead to an adequate deployment of the most promising systems. These topics will touch upon several research aspects, relevant for follow-up activities. Eventually, this may result in an improved impact assessment, which in turn can provide more knowledge to define a targeted contribution of the systems to policy goals (such as in the Dutch *Mobility Policy Document*).

6.1. Improving effect estimates

Several dimensions could be added to the effect estimates in studies that have been performed so far, in order to give a more scientifically sound motivation of predicted real life effects. This is the case for all systems discussed in this report, and will also apply to other/new systems for which relevant effects on speed may be reported in the future.

It is not sufficiently clear how possible side effects could influence real life performance of speed support systems, particularly in the case of long term usage and high vehicle equipment rates. It should be further investigated if and how any serious negative behavioural adaptation may develop. Interaction between equipped and non-equipped vehicles as a function of penetration rates should also be subject to study. The effects of speed support systems could vary substantially for different groups of drivers and this should be taken account of when setting up experimental groups for impact assessment studies. Passenger cars are mostly taken as the central objective for study. However, the technology can also be applied on other vehicle types like heavy goods vehicles, delivery vans and motorcycles. Vulnerable roads users (pedestrians, cyclists) are likely to benefit as well. In what situations and to what extent should be the subject of further research. In setting up experiments it is also recommended to perform ex-ante evaluations, for example with the method of hazard and operability analysis (HAZOP), which helps to define the full scope of problems that should be investigated.

More research should be done to systematically compare the effectiveness of different versions of the speed support systems (e.g. regarding HMI characteristics, and system settings). This research should pay more attention to the combined effects on safety, efficiency and the environment, and make steps towards a multi-objective optimization. Joint research opportunities should be explored with programmes such as 'Ecodriving' of SenterNovem (aiming at more economic, less polluting and safer driving styles), and with ongoing research into traffic flow optimization using floating car data and cooperative systems. More than is now the case, research should address speed support as a functional part of an integral driver support system (e.g. ISA combined with navigation systems, ACC, Lane Departure Warning systems).

Different research methodologies (field operational tests, instrumented vehicles, driving simulator, traffic simulation) can be used. Preferably the methods are tuned to each other in an overall impact assessment framework in which the merits of the different methodologies are combined. As evaluation of the systems in real traffic is very important for accurate impact assessment, many of the studies consulted for this report recommend more field operational tests and tests on a larger scale (see e.g AVV, 2007). The Innovation Programme of the Dutch Ministry of Transport, released in 2006, has also given this as an important recommendation for system evaluation, and for increasing awareness and obtaining support (Min. V&W, 2006).

Other than the importance of large scale field operational tests (also within TRANSUMO), good safety impact assessment also requires an evaluation of relevant real life crashes. This requires an implementation scale of the system concerned that is not likely to be achieved on short term (i.e. not within the timeframe of the TRANSUMO project). However, to this end useful experience can be obtained by investigating the effects of Electronic Stability Control (ESC), a vehicle dynamics technology, which has a substantial equipment rate in the vehicle fleet. Statistical analysis of accidents for which ESC is relevant, can give good insight into the impact assessment procedure for new systems, while making a contribution to research into the impact of vehicle technology in its own right.

6.2. Deployment processes

Successful deployment requires better understanding of the position of the different stakeholders. This may contribute to making the positions more compatible and the cooperation between the stakeholders more fruitful. For ISA it was shown that for better understanding and an increase of stakeholder acceptance, it is important that there is a strategy for research into acceptance which deals with communication, socio-political developments, and past successes or failures. Furthermore, research into stakeholder opinions regarding ISA should concentrate on an unambiguous methodology for the assessment of stakeholders' preferences, including changes in preferences over time. Individual stakeholder preferences should be assessed well, since averaging the preferences of different stakeholders is not sufficiently specific. It should also be investigated how the overall priority policy alternative can be deduced from different stakeholder preferences, for example, by taking into account stakeholder influence. Such a study will be performed within TRANSUMO.

Within implementation strategies there will be a continuous need for balance between individual and collective interests, and between market parties and government parties. Better understanding of the policy making process can directly influence the implementation scenarios. Further specification and testing of the adaptive policymaking approach for ISA are future challenges in this field. This should be focused on the development of systematic approaches to fully identify the vulnerabilities; the level of (un)certainty of these vulnerabilities and the trigger events and their values. One way to test the adaptive approach might be to use scenario and simulation gaming to compare the adaptive policymaking approach to more traditional policymaking approaches. After this learning phase, concrete steps should be made fast to actually start using it for the implementation of ISA, at the same time paying proper attention to the more traditional speed management measures. As part of the adaptive policy making, scenarios should be envisaged in which in-vehicle ITS for speed support becomes increasingly important, co-existing with other measures while adding efficiency, and on the longer term possibly replacing some of the more traditional measures.

A good basis for an ISA implementation strategy would be the establishment of a generally accepted framework for ITS policy at international, national and local level. All stakeholders involved should participate and it should be aimed at mutual cooperation. To achieve this, a road safety agreement for the implementation of ITS, with special focus on ISA, could be an appropriate form (at least in the Netherlands). Such an agreement should reduce uncertainties for all stakeholders about the pace and direction of developments.

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Appendix Illustration of outcomes of interest (policy making)

In general, policies are choices regarding a system in order to change the system outcomes in a desired way. The domain of interest here is the transportation system, defined by physical components (people or goods, means of transportation and infrastructure) and their mutual interactions (*Figure A.1*). The results of these interactions are called outcomes of interest, which are important for evaluation of policy measures. Outcomes of interest are, for example, the number of road accidents, level of congestion and level of emissions. Not all outcomes of interest are considered to be of equal importance to each stakeholder, so each stakeholder may have a different valuation of outcomes of interest.

Policymakers are able to impose changes on the transportation system and its outcomes of interest by implementing policies. The substance of these policies should take into account the stakeholder valuation of outcomes of interest. Another force that affects the transportation system is external forces, which are not under control of the policymaker but may influence the system significantly. External forces on the transport system involve, for example, demographic, economic, spatial, social and technological developments in society.

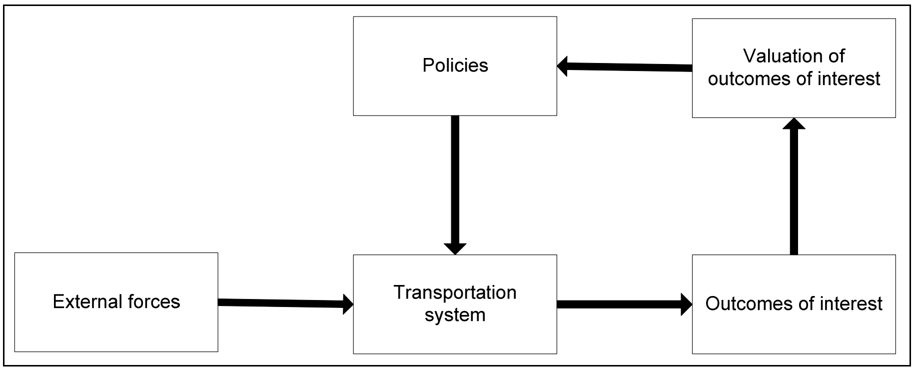

Figure A.1. *View on policymaking in the transportation domain (adapted from Marchau & Walker, 2004).*

This view on policymaking is adopted in this report as a view on implementation, assuming that implementation by the market (business cases) works the same way. In *Figure A.1* "policies" should then be replaced by "implementation strategies".

When Advanced Driver Assistance Systems (ADAS) are concerned there are uncertainties about the influence of external forces, the outcomes of ADAS implementation and the valuation of outcomes from ADAS implementation (Marchau & Walker, 2004). The latter two aspects are addressed in *Chapter 3*. Further implementation aspects are discussed in *Chapter 4*.