

Enhancing speed management by intelligent speed adaptation systems

Marchau, VAWJ; van Nes, N; Walta, L; Morsink, P

DOI

[10.1049/iet-its.2009.0038](https://doi.org/10.1049/iet-its.2009.0038)

Publication date

2010

Document Version

Final published version

Published in

IET Intelligent Transport Systems

Citation (APA)

Marchau, VAWJ., van Nes, N., Walta, L., & Morsink, P. (2010). Enhancing speed management by intelligent speed adaptation systems. *IET Intelligent Transport Systems*, 4(1), 3-11. <https://doi.org/10.1049/iet-its.2009.0038>

Important note

To cite this publication, please use the final published version (if applicable). Please check the document version above.

Copyright

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy

Please contact us and provide details if you believe this document breaches copyrights. We will remove access to the work immediately and investigate your claim.

Green Open Access added to TU Delft Institutional Repository

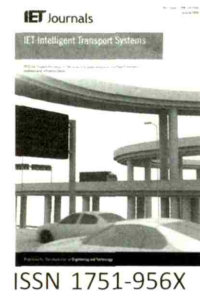
'You share, we take care!' - Taverne project

<https://www.openaccess.nl/en/you-share-we-take-care>

Otherwise as indicated in the copyright section: the publisher is the copyright holder of this work and the author uses the Dutch legislation to make this work public.

Published in IET Intelligent Transport Systems
 Received on 16th February 2009
 Revised on 15th July 2009
 doi: 10.1049/iet-its.2009.0038

Special Issue – selected papers from the 15th World
 Congress on ITS



Enhancing speed management by in-car speed assistance systems

V. Marchau¹ N. van Nes² L. Walta¹ P. Morsink³

¹Faculty of Technology, Policy and Management, Delft University of Technology, Jaffalaan 5, 2628 BX Delft, The Netherlands

²SWOV Institute for Road Safety Research, Duindoorn 32, 2260 BB Leidschendam, The Netherlands

³DHV B.V., Environment and Transportation, Laan 1914 no 35, 3818 EX Amersfoort, The Netherlands

E-mail: Nicole.Van.Nes@swov.nl

Abstract: Intelligent speed adaptation (ISA) systems support drivers to comply with the legal speed limits. This functionality is expected to become increasingly important in speed management if integrated well with more traditional speed management measures. Based on state-of-the-art scientific literature, this study describes the current knowledge on the effects of ISA and the willingness of stakeholders to adopt ISA. Although the expected effects of the various ISA types are promising and stakeholders are willing to adopt ISA, the large-scale deployment of ISA is still lacking. The main challenges with respect to ISA deployment relate to its social and political feasibility. Overall, a more active role of public authorities is recommended on ISA deployment, especially for ISA systems that actively intervene in the driving task.

1 Introduction

Speed management is a central theme in traffic management, aiming to optimise traffic in terms of safety, efficiency and effects on the environment. Speed management includes setting proper speed limits, improving homogeneity of the traffic flow and reducing speeding.

In terms of safety, inappropriate speeds for prevailing conditions and large speed differences are causal factors in many accidents. It has been estimated that in about 30% of fatal road accidents excessive speed is involved, making speed a crucial factor in road safety [1]. The exact relationship between speed and accidents, however, is complex and depends on several specific factors [2, 3]. In general, it can be stated that higher speeds and larger differences in speed increase accident risk and injury severity. For instance, for the Netherlands, it has been estimated that the number of severe road casualties can decrease by 25%, if 90% of car drivers would comply with the speed limits [4].

With respect to the environment, less speeding and more homogeneous traffic flows are also beneficial. Lower and more homogeneous speed and preventing frequent and abrupt accelerations reduce energy consumption, noise,

emissions of CO₂, NO_x and noxious dust. Interestingly, at the same time these factors also increase the comfort of driving. For the optimisation of accessibility and traffic flows, the situation appears less straightforward. There is some tension between the requirements for fast and for safe travelling, since at a first glance higher speed reduces travel times and increases accessibility in free-flow conditions, but decreases safety. However, this tension is not as large as it may seem initially [5]. At first because the maximum throughput of a road is generally achieved at a lower speed than in free-flow conditions [6], and unstable traffic flows can be stabilised by a lower speed which results in a higher average throughput. Secondly, a considerable part of congestion is caused by accidents, and the number of crashes decreases with lower and more homogeneous travel speeds (e.g. [7]).

Within speed management, safety measures are traditionally subdivided into the 3E's: engineering (e.g. roundabouts), enforcement (e.g. speed cameras) and education (e.g. public campaigns). Over time, these speed measures have been successful [8, 9]. However, many people still drive at speeds well above the speed limit, regardless of the type of road or the traffic circumstances [10]. Violation percentages ranging from 40 to 50% on

different types of roads are still very common in many European and non-European countries [6, 11]. Supported by a growing sense of urgency, there is a need for further progress in tackling the speeding problem. Consequently, there is a need for new types of measures or technologies to enable this progress.

Potential means for progress in speed management could be provided by the current developments in in-car driver assistance systems. A variety of driver assistance functionalities is being developed or already available, such as lane keeping assistance, distance keeping assistance and speed limit keeping assistance. The later functionality most directly influences the (intended or unintended) speeding behaviour of drivers, and is also known as intelligent speed adaptation (ISA).

ISA involves in-vehicle technology that continuously determines the position of a vehicle, then compares the vehicle speed to the posted speed limit at that location, and consequently gives some in-vehicle feedback about it to the driver. Different feedback strategies are used:

- informing ISA displays the speed limit and reminds the driver of speed limit changes,
- warning ISA gives a visual or auditory non-committal warning when the driver exceeds the limit,
- intervening ISA gives a counterforce on the gas pedal when the driver tries to exceed the speed limit and
- controlling ISA automatically limits the maximum speed of the vehicle to the speed limit.

The informing and warning ISA types (also referred to as SpeedAlert) are relatively simple; some route navigation systems already have this as an additional feature.

ISA can help to prevent drivers from making misjudgements, errors and unintentional violations. This is expected to improve compliance with the speed limits, and to add to the credibility and effectiveness of speed enforcement. In addition, in-car speed assistance systems with an integrated enforcement function can prevent intentional speed violations. Auto-policing, using in-vehicle technologies such as electronic vehicle identification (EVI) and black boxes [6], may make enforcement more effective and efficient. These systems are likely to increase the legitimacy of the limits, and, as a consequence, could further contribute to increase the credibility of speed enforcement. Furthermore, the possibility to give behavioural feedback may also provide opportunities for rewarding good behaviour, which may add to the system's effect [12].

In the last decades, there have been considerable advancements in ISA developments and the future

perspective of ISA seems very promising in terms of technological feasibility and potential contribution to traffic safety, efficiency and the environment. On the other hand, however, there is still large uncertainty about the real-world effects of ISA deployment and the conditions required for successful deployment [13, 14]. This paper aims at synthesising the current knowledge required for ISA deployment. It provides an insight into the current state of affairs of ISA systems, it presents their position within speed management, describes scientific evidence of predicted effects and discusses important aspects for deployment processes.

2 Reported effects of ISA

The current evaluations of ISA are mainly based on simulations and conditioned field tests. Implementation of ISA in real traffic has only been realised limited. Reported studies on ISA include different methodologies and data collection techniques including field operational tests (FOT), (single) instrumented vehicle experiments, driving simulator studies and traffic simulations. In this section, an overview is presented of the main results of a selection of studies regarding the overall effects of ISA on drivers' speeding behaviour, traffic safety, traffic efficiency and the environment.

2.1 Effects on speed

Most studies on the effects of ISA on speeding behaviour focus on effects on mean driving speed, the standard deviation of speed (speed variance) and the percentage of speed limit offenders as indicators. Generally, the results show that ISA reduces the mean speed and the speed variations. Table 1 provides an overview of the effects of ISA on speeding behaviour, based on the results of different types of studies, in different countries and with different types of ISA [15].

Since different studies show differences in the size and types of effects, only indications can be given of what may eventually be achieved. In general, ISA systems appear to have positive effects on the driving speed: a mean speed reduction of approximately 2–7 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 intervening ISA types being more effective. The only exception was found in [16] which investigated ISA on icy roads. As a result, the mean speed of ISA drivers slightly increased (approx. 1 km/h).

The effects of ISA on speed as reported above are not easily translated into effects on traffic safety, the environment and traffic efficiency. This is first of all because the (theoretical) knowledge on the exact relationship(s) between (microscopic) vehicle speed behaviour and (macroscopic) traffic flow behaviour is limited (e.g. [2]). Second, the experimental conditions in the consulted studies are

Table 1 Overview of ISA effects on mean speed, standard deviation of speed and speed violations in various studies

Study	Methodology	Country	ISA type	Effect on mean speed	Effect on speed variance	Effect on speed violations
[16]	simulator	FIN	controlling	↑	↓	?
[17]	simulator	UK	informing, controlling	↓	↓	?
[18]	simulator	NL	intervening	↓	↓	↓
[19]	instrumented vehicle	NL	warning	↓	↓	↓
[20]	instrumented vehicle	FIN	informing, warning, controlling	↓	?	↓
[21]	instrumented vehicle	NL	warning	?	?	↓
[22]	FOT	NL	controlling	↓	↓	?
[23]	FOT	DK	warning	↓	?	?
[24]	FOT	S	warning, intervening	↓	↓	↓
[25]	FOT	B	intervening	↓	↓	↓
[26]	FOT	AUS	intervening	↓	↓	↓

(↓ decrease, ↑ increase, ? not investigated)

different, that is their scale and the extent to which they represent real traffic. Finally, the different types of effects are often described separately, but they are also related: fewer crashes cause a reduction of congestion, which in turn has a beneficial effect on the environment.

2.2 Effects on traffic safety

Based on the reductions found in mean speed, speed variance and the percentage of speeding, ISA systems can potentially achieve high reductions in the incidence and severity of road accidents (e.g. [27]).

Although it is not easy to estimate the potential accident savings because of ISA in general, several studies have tried to do this for specific cases. A comprehensive attempt to calculate possible safety effects of various ISA systems is given by Carsten and Tate [28]. In this study, a distinction was made between:

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 used for the ISA. Static speed limits inform the driver about the posted, fixed speed limits. Variable speed limits informed the driver, in addition, about (lower) speed limits at special locations (e.g. road construction sites, pedestrian crossings, sharp curves and so on) and therefore the speed limits are dependent on the location. The dynamic ISA system uses speed limits that take account of the actual road and traffic conditions (weather, traffic density). Therefore beside depending on location the dynamic speed limits are also dependent on time.

Next, the relations between changes in speed and changes in injury accidents were modelled. A single relation for all roads was assumed, based on the best estimate by Finch [29]: 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 ISA system. For the automatically controlling ISA 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 [28]. Next, based on the national accident data and the literature (including some of the studies discussed in the previous paragraph), assumptions were made regarding the changes in 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 set by the system. The speed change of drivers with the voluntary automatic control system was assumed to be half of the speed change of drivers with the mandatory automatic

control system. The speed effects were then related to specific crash types and conditions for which the systems would be effective. Subsequently, the crash savings were estimated, assuming a 100% equipment rate of the systems over the entire road network.

Considerable effects were obtained for all types of ISA systems. There is a large variation though; informing systems appear to have a much smaller effect than mandatory automatic control systems. Static speed limits also have a smaller effect than dynamic speed limits. The largest effects are expected from the dynamic mandatory automatic controlling ISA, which could give a 36% reduction of injury crashes and a 59% reduction of fatal crashes. Even the static informing ISA would still reduce these crash types with, respectively, 10 and 18% [28].

Some other studies [4, 26, 30] used Nilsson's power model [31] to estimate accident savings because of ISA. For instance, for The Netherlands it has been estimated that the annual fatalities and serious injuries would reduce by 25%, if all the vehicles would be equipped with a static mandatory automatic control system [4]. This corresponds to the results obtained in [28]. Using the same approach, a 34% reduction in fatal crashes and a 27% reduction in injuries was predicted 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 [22]. In an Australian study [26], the Nilssons' power model was used to estimate accident reductions from the driving data in the Australian trial. The combination of warning and intervening ISA was expected to give reductions of injury crashes ranging from 2.8% (100 km/h zones) to 5.8% (60 km/h zones), and reductions of fatal crashes ranging from 3.8% (100 km/h zones) to 7.6% (60 km/h zones). If ISA were combined with following distance warning, an additional 1–1.5% reduction 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, as they were already driving at relatively low speeds without ISA.

2.3 Effects on the environment

ISA is expected to be beneficial for the environment because of the estimated speed reduction and the smaller speed variance. The results of the Swedish trial in the city of Lund, showed reduced emissions mainly for dual carriageways and 50 km/h speed limits. The average reduction for CO 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 [32]. In the Australian trial [26], a decrease of fuel consumption and CO₂ emissions (both 4%) was found for a combination of ISA and following distance warning, not for both systems separately, and only in 80 km/h zones. 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 [33] the ISA effects on fuel consumption and emissions were modelled for different road network conditions. The total fuel consumption was found to gradually decrease 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 roads and 1% for motorways. They also found that the emissions of CO, NO_x and HC varied only by $\pm 2\%$ for all ISA penetration rates.

2.4 Effects on traffic efficiency

In the Swedish field trials, the effect of ISA on travel times was found to be neutral [24]. In a microscopic simulation study [33] the outcomes were somewhat further differentiated. In addition, a neutral effect on travel time was found for ISA, expressed by the total travel time of vehicles in the network. However, 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, because of a lower average speed. In [34] an explorative micro-simulation study of the effects of ISA in a lane-drop situation (from three to two driving lanes) on a motorway was carried out. A more homogeneous traffic flow because of ISA was found, based on less speed variations within and in-between lanes, and a more balanced division of flow over the lanes. However, a lower maximum traffic throughput at the bottleneck was also observed, which was probably caused by 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.

3 Conditions for achieving ISA effects

It is important to be aware that in most studies, the estimated effects for ISA assume 100% penetration rates. In addition, the estimates do not incorporate possible side effects that may reduce the predicted effects, such as behavioural adaptation. Risk compensation may for example lead to closer following distance [35]; 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 more dangerous merging), as well as large speed differences between equipped and non-equipped vehicles (e.g. [36]). More research, for example large FOT that also investigate long-term effects, should be done to assess the impact of these factors (e.g. [37, 38]).

For ISA it has been shown 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. More credible speed limits may contribute to resolving this trade-off between acceptance and effectiveness. A simulator study on the effects of improving speed behaviour by ISA and using more credible speed limits shows that the informative ISA system as used in this study as well as speed limit credibility significantly improved speed behaviour [39]. Non-ISA users appear to be more sensitive to the credibility of speed limits than ISA users. In addition, speed limit credibility may have an effect on the acceptance of the ISA system: when speed limit credibility is high, the corrections/warnings are likely to be perceived as more reasonable and, hence, better accepted. Apart from the type of system (including the type of feedback system), user acceptance of ISA depends on driver characteristics. It seems that drivers whose speed behaviour would benefit most from ISA, accept it the least [40]. Regarding the road type, there are indications that ISA would be most widely accepted in low-speed areas, and on 80 km/h roads.

Apart from users, ISA deployment requires that other stakeholders undertake actions. The most important ones in this context are probably the automotive industry and public authorities. The preferences of these stakeholders with respect to ISA are presented in Table 2. This table is based on the results from a large literature survey on stakeholder positions regarding ISA (for an overview of this study see [15]). In summary it was found that:

- Most of the effort in the assessment of individual ISA stakeholder preferences concentrated on the user.
- The three main stakeholders (authorities, users and industry) are found to have different preferences.
- 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

Table 2 Overview of stakeholder positions

ISA	Preference amongst different actors		
	Authorities	Users	Industry
warning	+++	++	+
intervening	+	+	+/-
controlling	+	+/-	-

- , 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)

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 ISA alternatives.

Promising effects and clear and compatible stakeholder positions are important starting conditions for successful deployment of ISA. However, up until now these positive prospects are not sufficient for the deployment of ISA on a large scale. Apparently, deployment of ISA requires more knowledge than is currently provided. In the next section, this knowledge will be explored.

4 Deployment of ISA

Deployment of ISA concerns issues such as who is intended to be using ISA, which type of ISA is to be used, on which roads and under which traffic conditions. As a result of the multiple deployment options available (i.e. which users, which ISA type, market or policy driven and so on), it is not yet clear which course the deployment of ISA should or would take.

In general, deployment of ISA can be market driven, policy driven or a combination of both, which is different from the more 'traditional' speed measures that are largely policy driven.

Successful market-driven deployment of ISA is likely to be expected when there is a good return on investment. Successful policy-driven ISA deployment is likely when the societal benefits of ISA are expected to be large (e.g. traffic safety, environment and traffic efficiency). Both deployment schemes strongly depend on the rate of adoption of ISA among crucial ISA stakeholders (i.e. car drivers, automotive industry and public authorities). In general, there are three general requirements for the adoption of transport innovations: technical feasibility, social feasibility and political feasibility [41]. In the following, the status of these three types of feasibility regarding ISA is explored, and potential measures are suggested to influence this status.

4.1 Technical feasibility of ISA

The technical feasibility concerns the technical performance of the ISA system. So far, several types of ISA have been tested in pilots and informative and warning types of ISA are available as features on navigation systems. The main issue regarding the technical feasibility of ISA deployment is the development and maintenance of a high-quality digital map with speed limits. The development of such a map is a huge effort, and as speed limits keep changing (temporarily or permanently), the map needs continuous maintenance to be kept up to date (e.g. [42]). A reliable speed limit map is an important prerequisite for ISA deployment. Furthermore, the reliability of GPS,

particularly in urban areas, is a problem that remains to be solved. Currently, navigation devices are being tested with a built-in camera that is able to recognise and read speed limit signs when driving, that is mobile mapping. This development may overcome the drawbacks of speed limit maps. It is not clear, however, which of these systems, or maybe a combination, will become dominant.

4.2 Social feasibility of ISA

Social feasibility of a transport innovation is mainly influenced by: (i) the perception of the problem the innovation addresses, (ii) the perceived effectiveness of the innovation and (iii) the perceived distribution of costs and benefits of the deployed innovation [41].

4.2.1 The perception of the problem ISA addresses: The problem that ISA addresses is the negative effect of excessive and inappropriate speed. Speeding is generally acknowledged as a problem by potential users of ISA, that is people with a driver's license (e.g. [25]). In addition, potential users generally indicate that taking action against speeding should be prioritised for (mixed traffic) urban areas and rather than for motorways (e.g. [43]).

4.2.2 The perceived effectiveness of ISA: As discussed in Section 2, the potential effectiveness of ISA to improve traffic safety is promising. However, it is the perception of these effects that influences social feasibility. In the case of ISA, the perceived effects are not always in line with what is expected from effect studies. For example, Risser and Lehner [44] showed that car drivers and pedestrians perceived traditional speed measures, like speed humps, as more effective than ISA towards achieving an appropriate speed. In addition, Molin and Marchau [45] found that warning ISA was perceived as safer than limiting ISA, but safety might have been interpreted as inherent safety of the system by the respondents.

4.2.3 The perceived distribution of costs and benefits: The perceived distribution of costs and benefits is something that may need to be carefully studied before taking action towards ISA deployment. For example, two potential benefits of ISA, which are directly related to speeding, are avoiding speeding tickets and reducing crash risk. The difference between these two is that avoiding speeding tickets is a clearly perceived benefit that is considered to be of daily use by car drivers, whereas the reduction of crash risk is considered much less of direct use by car drivers as this is much more abstract in its nature, there is still a risk, but it is smaller.

In addition, the perception of the benefits will also be different for drivers that intend to speed and for drivers that do not. This indicates that some drivers may be more willing than others to bear the costs for ISA. This willingness may also differ between different types of ISA,

depending on what the perceived effects are. On the other hand, there are companies with a direct professional interest in traffic safety, for example in terms of reduced operational costs or safety culture, such as transport companies, insurance companies and fleet owners. For them it may be more straightforward to invest in ISA deployment within their vehicle fleets.

4.3 Political feasibility of ISA

The three factors that mainly influence political feasibility are: the prevailing perspective of people on the transportation system (i.e. similar to sanctioned discourse), experience with similar innovations and decision-making procedures [41]. The latter is not being considered here, since it is not particularly different for ISA than for other policy measures regarding the transportation system.

The prevailing perspective from which people view and act in relevant parts of the transportation system is a very important indicator for what is politically feasible. A prevailing perspective often referred to with respect to deployment of ISA is that the personal car is seen as a cultural symbol of freedom, including, for example, free choice of destination and free choice of speed. This can be illustrated by the fact that limitations to driving freedom are usually not very well accepted (see Section 3). Car manufacturers keep building cars of which the maximum speed is far beyond the current speed limits. Regarding the political feasibility this means that controlling ISA may be the hardest to deploy, as it leaves the least choice to the driver.

Relevant experience with respect to ISA deployment is available through the introduction of mandatory speed limiters in trucks. While the effects of these speed limiters have not been evaluated yet, this policy seems to be successful in keeping trucks to the speed limit in the Netherlands. There is no experience yet with ISA being deployed on a large scale.

Summarising, the political feasibility of those types of ISA that are most limiting with respect to driving freedom is questionable. This explains the current attention for deployment of informative or warning types of ISA that are generally less effective.

4.4 Main issues concerned with deployment of ISA

Based on the discussion of the technical, social and political feasibility of ISA a number of suggestions could be made to increase the chance of success for deployment of ISA. First of all, the awareness of the expected effects of ISA among its potential users should be increased, in order to update their perceived effects. Second, the distribution of benefits and costs, as part of a deployment strategy, should match the perceived distribution of benefits and costs by the potential users of ISA. This will also determine if market

deployment, policy deployment or a combination of both is the most feasible deployment strategy. If the general perception is that ISA is more beneficial for society rather than for individual users, public authorities may have to bear the costs in order to increase adoption (as market deployment is probably not feasible in this situation). Third, the current perspective of 'freedom of car driving' should become part of a debate. It requires a substantial amount of time and effort to change this perspective, and it is unclear whether this is even possible on a relatively short term. In this respect, it is important to realise that introducing controlling ISA for speed offenders may confirm the current perspective by representing limitation of driving freedom as a punishment. It is likely to be more appealing to drivers when ISA is presented as a positive and supporting instrument for safe driving and preventing speeding tickets.

Finally, if ISA would be deployed in any country, this could influence the perceptions about ISA in other countries, and consequently influence social and political feasibility.

5 Conclusions and recommendations

This paper has provided an overview of the available knowledge on ISA in order to improve future speed management. This knowledge involves the effects of ISA on speed, safety, environment, and traffic efficiency and the conditions for achieving these effects, such as the acceptance of ISA by users and other crucial stakeholders. This knowledge is next translated into deployment strategies of ISA.

5.1 Effects of ISA

The effects of ISA have been studied in FOT, instrumented vehicle experiments, driving simulator studies and traffic simulations. Based on an extensive overview of studies it can be concluded that ISA generally has a positive effect on speeding. In relation, the effects of ISA on traffic safety and the environment are also positive. The effects on traffic efficiency generally seem to be neutral. However, all these results depend on which type of ISA is studied, and the assumed percentage of vehicles equipped with ISA. More intervening types of ISA are generally more effective with respect to speeding and traffic safety, which are the most important effects of ISA. In addition, more credible speed limits and dynamic speed limits can increase the effectiveness of ISA since it increases the acceptance and compliance of users to the speed limits.

5.2 Conditions for achieving ISA effects

Several studies on effects do not take into account possible side effects of ISA on driving behaviour, such as risk compensation. More attention to these side effects is required as these could counteract initial benefits of ISA.

The most important stakeholders in ISA deployment are the user, the public authorities and the automotive industry. The preferences of these stakeholders with respect to ISA are of major importance for ISA deployment, since their decisions will likely affect the speed and direction of future ISA deployment. Current research on stakeholder preferences shows that the authorities are more positive about ISA than the potential users and the automotive industry, and all stakeholders prefer warning ISA above intervening and controlling ISA. It seems that the freedom of driving plays an important role in preferences for ISA alternatives.

5.3 Deployment of ISA

The main issues regarding ISA deployment are that the effects of ISA are currently perceived less positive than reported by the studies described by this paper; the perceived distribution of costs and benefits of ISA; the current perspective on driving freedom [as a result of which ISA is perceived as limiting (or even punishing) instead of enhancing], and the lack of experience with ISA in other countries. These issues will heavily influence the way ISA will be deployed in the future, that is market driven and/or government driven.

Based on these findings, the following recommendations regarding the deployment of ISA can be made. Although for warning ISA the expected effects are expected to be lower than for intervening ISA and controlling ISA, the effects are still positive. Besides, this type of ISA is preferred by the most important stakeholders: the users, the authorities and the industry. Hence, warning ISA seems ready for large-scale deployment. Possible barriers are the reliability of the technology (e.g. speed maps), and the uncertainty about the side effects of warning ISA on the longer. However, these factors are relatively less important for a warning system. The discussion whether market or government deployment is most feasible for warning ISA deployment can be illustrated by the distribution of costs and benefits. If the users perceive warning ISA as beneficial for them as individual users, they might likely be more willing to adopt ISA voluntary, and a market-driven deployment seems feasible. If, on the other hand, users perceive warning ISA as mainly beneficial for society and not for them as individual users, a government-driven deployment seems more feasible.

With respect to intervening and controlling ISA, the deployment options can be explored by the government that mandate these systems for specific groups of users, such as speed offenders, and inexperienced or novice drivers. If, in turn, it is found to be desirable that intervening or controlling ISA are deployed among larger groups of users, there are a number of actions that are presumed to be necessary. First of all, user awareness of the positive effects of these ISA systems may need to be increased. Second, the current perspective on driving freedom will need to be changed. Finally, positive

experiences with deployment of intervening or controlling ISA in other countries need to be communicated widely.

6 Acknowledgment

The paper has been composed with support of the knowledge investment programme TRANSUMO (TRANSition towards SUsustainable MOBility, more information is available on www.transumo.nl).

7 References

- [1] TRB: 'Managing speed. Review of current practice for setting and enforcing speed limits'. TRB Special Report 254 (Transportation Research Board, 1998)
- [2] AARTS L., VAN SCHAGEN I.N.L.G.: 'Driving speed and the risk of road crashes; a review', *Accident Anal. Prev.*, 2006, **38**, (2), pp. 215–224
- [3] ELVIK R., CHRISTENSEN P., AMUNDSEN A.: 'Speed and road accidents; an evaluation of the power model' (Institute of Transport Economics TØI, 2004)
- [4] OEI H.-L.: 'Safety consequences of intelligent speed adaptation ISA', R-2001-11, SWOV, 2001
- [5] ARCHER J., FORHERINGHAM N., SYMMONS M., CORBEN B.: 'The impact of lowered speed limits in urban and metropolitan areas' (Monash University Accident Research Centre, 2008)
- [6] OECD/ECMT: 'Speed management'. Organisation for Economic Co-operation and Development OECD/European Conf. on Ministers of Transport ECMT, 2006
- [7] TOLEDO T., ALBERT G., HAKKERT S.: 'Impact of active speed limiters on traffic flow and safety: simulation-based evaluation', *Transp. Res. Rec.*, 2007, **2019**, pp. 169–180
- [8] WEGMAN F.C.M., DIJKSTRA A., SCHERMERS G., VAN VLIET P.: 'Sustainable safety in The Netherlands: the vision, the implementation and the safety effects'. Third Int. Symp. on Highway Geometric Design, 2005
- [9] PILKINGTON P., KINRA S.: 'Effectiveness of speed cameras in preventing road traffic collisions and related casualties: systematic review', *Br. Med. J.*, 2005, **330**, pp. 331–334
- [10] CONSORTIUM S.: 'European drivers and road risk. Part 1, report on principal results'. (INRETS, 2004)
- [11] ACHTERBERG F.: 'Raising compliance with Road Safety Law' (European Traffic Safety Council ETSC, 2007)
- [12] HAGENZIEKER M.: 'Rewards and road user behaviour' (Leiden University, Leiden, The Netherlands, 1999)
- [13] MORSINK P.L.J., WEGMAN F.C.M.: 'Vision on ITS within sustainable safety based policy in the Netherlands'. Thirteenth World Congress and Exhibition on Intelligent Transport Systems and Services, 2006, paper no. 1110
- [14] European Commission: 'Final report of the safety working group on road safety'. European Commission, Directorate General Information Society Technologies, 2002
- [15] MORSINK P.L.J., GOLDENBELD C., DRAGUTINOVIC N., MARCHAU V., WALTA L., BROOKHUIS K.: 'Speed support through the intelligent vehicle' (SWOV, 2006)
- [16] PELTOLA H., KULMALA R.: 'Weather related ISA – experience from a simulator'. Seventh World Congress on Intelligent Transport Systems, 2000
- [17] COMTE S.: 'Evaluation of in-car speed limiters: simulator study'. Working Paper R 3.2.1, MASTER project, 1998
- [18] HOGEMA J.H., ROOK A.M.: 'Intelligent speed adaptation: the effects of an active gas pedal on driver behaviour and acceptance'. Report TM-04-D011, TNO, 2004
- [19] BROOKHUIS K., DE WAARD D.: 'Limiting speed, towards an intelligent speed adapter (ISA)', *Transp. Res. F: Traffic Psychol. Behav.*, 1999, **2**, (2), pp. 81–90
- [20] PAATALO M., PELTOLA H., KALLIO M.: 'Intelligent speed adaptation – effects on driving behaviour'. Traffic Safety on Three Continents Conf., 2001
- [21] VVN: 'ISA test with volunteers' (Veilig Verkeer Nederland & SenterNovem, 2006)
- [22] AVV: 'Evaluatie Intelligent SnelheidsAanpassing (ISA): het effect op het rijgedrag in Tilburg' (AVV, 2001)
- [23] LAHRMANN H., MADSEN J.R., BOROCH T.: 'Intelligent speed adaptation: development of GPS based system and field trial of the system with 24 test drivers'. Eighth World Congress on Intelligent Transport Systems, 2001
- [24] BIDING T., LIND G.: 'Intelligent speed adaptation (ISA); results of large-scale trials in Borlänge, Linköping, Lund and Umeå during 1999–2002'. Publication 2002:89 E, Swedish National Road Administration SNRA, 2002
- [25] VLASSENROOT S., BROEKX S., MOL J.D., PANIS L.I., BRIJS T., WETS G.: 'Driving with intelligent speed adaptation: final results of the Belgian ISA-trial', *Transp. Res. A: Policy Pract.*, 2007, **41**, (3), pp. 267–279
- [26] REGAN M.A., TRIGGS T.J., YOUNG K.L., ET AL.: 'On-road evaluation of intelligent speed adaptation, following distance warning and seatbelt reminder systems: final results of the TAC SafeCar project' (Monash University Accident Research Centre, 2006)

- [27] PROSPER: 'Final report, project for research on speed adaptation policies on European roads (PROSPER)'. Project No. GRD2-2000-30217, 2006
- [28] CARSTEN O.M.J., TATE F.N.: 'Intelligent speed adaptation: accident savings and cost-benefit analysis', *Accident Anal. Prev.*, 2005, **37**, (3), pp. 407–416
- [29] FINCH D.J., KOMPFFNER P., LOCKWOOD C.R., MAYCOCK G.: 'Speed, speed limits and accidents'. TRL Project Report 58, TRL, 1994
- [30] KRAAY J.H.: 'The Netherlands traffic and transport plan: road safety with a special focus on speed behaviour'. ICTCT Workshop, 2002
- [31] NILSSON G.: 'Traffic safety dimensions and the power model to describe the effect of speed on safety' (Lund Institute of Technology, Lund University, Lund, Sweden, 2004)
- [32] VARHELYI A., HJALMDAHL M., HYDEN C., DRASKOCZY M.: 'Effects of an active accelerator pedal on driver behaviour and traffic safety after long-term use in urban areas', *Accident Anal. Prev.*, 2004, **36**, pp. 729–737
- [33] LIU R., TATE J., BODDY R.: 'Simulation modelling on the network effects of EVSC. Deliverable 11.3. of external vehicle speed control project' (Institute for Transport Studies, University of Leeds, 1999)
- [34] HOGEMA J., SCHUURMAN H., TAMPERE C.M.J.: 'ISA effect assessment: from driving behaviour to traffic flow'. ICTCT Workshop, 2000
- [35] COMTE S.L.: 'New systems: new behaviour?', *Transp. Res. F*, 2000, **3**, (2), pp. 95–111
- [36] VÁRHELYI A., MÄKINEN T.: 'The effects of in-car speed limiters: field study', *Transp. Res. C*, 2001, **9**, (3), pp. 191–211
- [37] VARHELYI A., HJALMDAHL M., HYDEN C., DRASKOCZY M.: 'Effects of an active accelerator pedal on driver behaviour and traffic safety after long-term use in urban areas', *Accident Anal. Prev.*, 2004, **36**, pp. 729–737
- [38] HJALMDAHL M., VARHELYI A.: 'Speed regulation by in-car active accelerator pedal; effects on driving behaviour', *Transp. Res. F*, 2004, **7**, pp. 77–94
- [39] VAN NES N., HOUTENBOS M., VAN SCHAGEN I.: 'Improving speed behaviour: the potential of in-car speed assistance and speed limit credibility', *IET Intell. Transp. Syst.*, 2008, **2**, (4), pp. 323–330
- [40] JAMSON S.: 'Would those who need ISA, use it? Investigating the relationship between drivers' speed choice and their use of a voluntary ISA system', *Transp. Res. F*, 2006, **9**, pp. 195–206
- [41] FEITELSON E., SALOMON I.: 'The political economy of transport innovations', in BEUTHE M., HIMANEN V., REGGIANI A., ZAMPARINI L. (EDS.): 'Transport developments and innovations in an evolving world' (Springer, Berlin, 2004)
- [42] VLASSENROOT S., DE MOL J., DEDENE N., WITLOX F., MARCHAU V.: 'Developments on speed limit databases in flanders: a first prospective'. Proc. 15th World Congress on ITS, ITS Europe, 2008
- [43] MARCHAU V., VAN DER HEIJDEN R., MOLIN E.: 'Desirability of advanced driver assistance from road safety perspective: the case of ISA', *Safety Sci.*, 2005, **43**, pp. 11–27
- [44] RISSER R., LEHNER U.: 'Acceptability of speeds and speed limits to drivers and pedestrians/cyclists' (CEC DG-TREN, 1998)
- [45] MOLIN E., MARCHAU V.: 'User perceptions and preferences of advanced driver assistance systems', *Transp. Res. Rec., J. Transp. Res. Board*, 2004, **1886**, pp. 119–125