ISA implementation and uncertainty: A literature review and expert elicitation study

J.W.G.M. van der Pas\textsuperscript{a,}\textsuperscript{*}, V.A.W.J. Marchau\textsuperscript{a}, W.E. Walker\textsuperscript{b,1}, G.P. van Wee\textsuperscript{c}, S.H. Vlassenroot\textsuperscript{a,c}

\textsuperscript{a} Delft University of Technology, Transport Policy and Logistics Organization Department, PO Box 5015, 2600 GA Delft, The Netherlands
\textsuperscript{b} Delft University of Technology, Policy Analysis Department, PO Box 5015, 2600 GA Delft, The Netherlands
\textsuperscript{c} Institute for Sustainable Mobility (IDM), Ghent University, Vrijdagmarkt 10/301, 9000 Gent, Belgium

\textbf{A R T I C L E   I N F O}

Article history:
Received 11 September 2009
Received in revised form 19 October 2010
Accepted 29 November 2010

Keywords:
ISA
ISA implementation
Uncertainty
Expert opinion

\textbf{A B S T R A C T}

Each day, an average of over 116 people die from traffic accidents in the European Union. One out of three fatalities is estimated to be the result of speeding. The current state of technology makes it possible to make speeding more difficult, or even impossible, by placing intelligent speed limiters (so called ISA devices) in vehicles. Although the ISA technology has been available for some years now, and reducing the number of road traffic fatalities and injuries has been high on the European political agenda, implementation still seems to be far away. Experts indicate that there are still too many uncertainties surrounding ISA implementation, and dealing with these uncertainties is essential for implementing ISA. In this paper, a systematic and representative inventory of the uncertainties is made based upon the literature. Furthermore, experts in the field of ISA were surveyed and asked which uncertainties are barriers for ISA implementation, and how uncertain these uncertainties are. We found that the long-term effects and the effects of large-scale implementation of ISA are still uncertain and are the most important barriers for the implementation of the most effective types of ISA. One way to deal with these uncertainties would be to start implementation on a small scale and gradually expand the penetration, in order to learn how ISA influences the transport system over time.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

In 2007, approximately 42,600 people were killed in road traffic accidents in the European Union (EU) and over 1.7 billion people were injured (European Road Safety Observatory (ERSO), 2008). Research shows that roughly one-third of these accidents are caused by speeding (Organisation For Economic Co-Operation and Development (OECD), 2006). Although the number of traffic fatalities within the EU is declining, recent figures show that the current rate of decline is far from sufficient to meet the goals for 2010 (EU Press Office, 2006; ETSC, 2006).

Speed management policies can be categorized according to the three E’s: Enforcement, Education, and Engineering (infrastructure and vehicle engineering). Analysis of speed reducing measures taken in the past shows that most of the three E measures are being used. The success of these measures has clearly been shown in practice, and different studies have made clear the costs and benefits of most of these measures (for an overview, see Elvik and Vaa, 2004). However, despite the fact that in-vehicle technologies might be able to replace other measures in a more effective and efficient way, vehicle design measures (vehicle engineering) aimed at reducing speed are underused.

A heavily researched and promising speed management measure that qualifies as a vehicle engineering solution is Intelligent Speed Adaptation (ISA). ISA is a system that supports drivers in avoiding speeding by continuously comparing the driving speed to the prevailing speed limit. In case of speeding, the ISA system can warn the driver (e.g. with audio visual signals), assist the driver (e.g. with a haptic throttle, which provides resistance above the speed limit), or even restrict the driver from going faster (e.g. the dead throttle, which makes it impossible to go faster than the local speed limit). In addition to categorization by the level of intervention the system gives, ISA can be categorized by the type of speed limit information it uses (static speed limits or dynamic speed limits), and whether it can be switched off by the driver (overridable vs. non-overridable). In this paper, we mainly use the level of inter-
In general, uncertainty can be defined as "any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system" (Walker et al., 2003). In our specific case, this comes down to missing knowledge regarding the implementation of ISA. There are many different ways of categorizing uncertainty (see e.g., Van Asselt, 2005; Morgan and Henrion, 1990). We apply the uncertainty framework introduced by Walker et al. (2003), because it was specifically designed to be applied to policy decision problems. Furthermore, it has been applied successfully in the transport policy domain in the past. For the case of ISA implementation, we define the transport policy domain or transport system by distinguishing its physical components (e.g., people, goods, vehicles, and infrastructure) and their mutual interactions (see e.g., Agusdinata et al., 2009; Marchau et al., 2010).

The Walker, et al. uncertainty categorization is based upon the analytical framework used in policy analysis (PA) (Walker, 2000). Using the PA framework, a categorization of uncertainties surrounding the choice of a policy using model-based policy analysis can be derived (see Fig. 1). In the context of transport, uncertainty regarding what policy to choose can be split up into (1) uncertainty about the model’s estimates of the transport system’s outcomes which are related to the objectives of policymakers and stakeholders (e.g., traffic safety, emissions, costs), and (2) uncertainty about the valuation of the outcomes (the relative importance given to the outcomes by crucial stakeholders, including policymakers).

The left branch of the tree of Fig. 1 shows the uncertainty about the model’s outcomes, which can result from uncertainty about external forces and/or uncertainty about system responses to the external forces (resulting from uncertainty regarding the relevance of the external forces or the values for the relevant external forces). External forces are forces outside the transport system that can affect the structure of the transport system and are not controllable by the policymaker but may influence the system significantly (e.g., economic and demographic developments affecting the transportation system). There can also be uncertainty about how the transport system responds to the external forces and to policies. Uncertainty about the system response might be due to uncer-

**Fig. 1.** Categorization of uncertainty (derived from Marchau and Walker, 2002).
tainty about the structure of the model and/or uncertainty and/or uncertainty about the model’s parameters.

The second category of uncertainty, shown in the right branch of the uncertainty tree (Fig. 1) refers to the valuation of the model’s outcomes. One can distinguish uncertainty about the stakeholder configuration (e.g. uncertainty on who the most important stakeholders are) and uncertainty about how these stakeholders value the various model outcomes. These values may change over time in unpredictable ways, leading to different valuations of future outcomes than those made in the present. Furthermore, new stakeholders can appear on the stage or the importance of stakeholders may change. But, these changes are also uncertain. The framework presented in Fig. 1 will be used throughout this paper to identify and structure the uncertainties surrounding the implementation of ISA.

2.2. Literature review methodology

In order to identify the uncertainties surrounding the implementation of ISA, we performed an extensive literature review. Although very insightful literature studies regarding ISA have been performed (see e.g. Jamson et al., 2006), our review differed in two important ways from the existing studies. First, and most important, we focused on the uncertainties surrounding ISA implementation from the policymaking perspective. Our underlying assumption is that the uncertainties surrounding ISA implementation are major barriers for policymakers and market parties to start implementing ISA. Second, we used results of the literature review to validate and extend the results using expert elicitation that, for each uncertainty, gives insight into the importance of the uncertainty as a barrier to implementation and its level of uncertainty.

The relevant literature was identified by searching different scientific databases (e.g. Scopus, Web of Science) using a list of keywords (e.g. ISA; speed limiter; etc.). In addition, the references of relevant publications were analyzed as well (“snowball” method). This resulted in a list of 187 publications of relevant ISA research.

2.3. Expert elicitation methodology

Given the uncertainties that resulted from the literature review, this section discusses sub-questions 2 and 3 (the level and importance of the uncertainties), which could not be answered using literature because the questions are hardly addressed at all in the literature. We designed a Web-based questionnaire and invited experts from all over the world to fill it in. We used a Web-based questionnaire for several reasons: it is an easy way to approach international respondents, a fast way of collecting data, and facilitates data-analyses (Sills and Song, 2002).

To elicit how large the experts thought the uncertainties were (sub-question 2), we used the level of uncertainty as introduced by Walker et al. (2003). The experts were able to choose among five levels of uncertainty, ranging from fully determined to fully uncertain:

1. Fully determined: there is no uncertainty regarding the subject. (i.e. there is perfect understanding of the subject.)
2. Statistical uncertainty: there is a lot of information about things that can happen and their likelihood. (i.e. there is a vast amount of empirical information on the subject.)
3. Scenario uncertainty: it is understood how the main mechanisms work, the range of things that can happen is known, but they cannot be ranked because the likelihood is unknown. (i.e. we have limited information on the subject.)
4. Recognized ignorance: there are some clues regarding the subject; but it is known that there are still things that are unknown. (i.e. there is little information on the subject.)
5. Fully uncertain: There is no clue about the subject and there is no knowledge about what can happen. (i.e. there is no information on the subject.)

In addition to the level of uncertainty, each of the experts was asked about the extent to which they thought the uncertainty was a barrier for implementation of ISA (sub-question 3). We distinguished four barrier levels: no, minor, medium, and major barrier for implementation.

Both these questions were asked for all uncertainties associated with the three ISA categories: (1) Warning ISA (speed alert): ISA that displays the speed limit and warns the driver using an audio/visual feedback in case of speeding, (2) Assisting ISA (haptic throttle): ISA that intervenes with the driving task by limiting the speed in case of speeding but which is still overridable (for instance by providing an overridable counter force on the throttle in case of speeding), and (3) Restricting ISA (speed limiter): ISA that restricts the vehicle speed to the speed limit (non-overridable).

In addition, the experts to ask for their opinions on:

- the most important uncertainties;
- the most important barriers;
- what they thought should be added to the list of uncertainties;
- what they thought should be added to the list of barriers.

3. Identifying the candidate uncertainties surrounding the implementation of ISA

3.1. Results of the literature review

We identified the uncertainties regarding ISA implementation addressed in the literature by applying the uncertainty categorization shown in Fig. 1. In the remainder of this section, we discuss the most important uncertainties per category. Looking at Fig. 1, the order of discussion will be from left to right, starting with a discussion of uncertainties regarding external forces and ending with a discussion of uncertainties regarding the evaluation of outcomes.

3.1.1. Uncertainty regarding the relevance and values of external forces

The effects of external forces on the transport system are generally not included as part of ISA research. However, they have been included in other research, and a lot of research has been done on identifying the relationship between external forces (e.g. economy, demography, ecology) and the transport system (see e.g. Button and Hensher, 2001). We found only two studies into uncertainty regarding the relevance and values of external forces for ISA, both by Carsten and Tate (2000) and Carsten et al. (2008). In their cost-benefit analyses of ISA, they included assumptions representing different sets of economic developments. However, the effect of other external forces, such as technological developments, demographic changes, and policy decisions from ministries besides transport are not considered. This could be essential information needed for policymaking for ISA implementation. Moreover, the research is specific to the United Kingdom, making it hard to use for policy decisions in other countries. (It is difficult to assess which results are ISA system specific, scenario specific, country specific, etc., so application of the results for policy decisions in other countries is difficult.) From the above, we conclude that the relevance and values of external forces for the implementation of ISA are highly uncertain.
3.1.2. Uncertainty regarding the system response to external forces and policies – model structure

3.1.2.1. Uncertainty regarding the effect of ISA on speed choice behavior. Most of the research related to the system response to external forces and policies has focused on the uncertainties regarding the effect of ISA on driver behavior (and, more specifically, speed choice behavior) and the driver behavior’s effect on the outcomes of interest (e.g., number of fatalities, number of accidents, CO₂ emissions). As noted before, it is hard to compare these research results, due to differences in research approach and underlying assumptions. Research into the effect of ISA on speed choice behavior differs according to: (a) the effect of different types of ISA, (b) the effect of different types of roads, (c) the effect of different types of drivers, including non-ISA drivers, (d) short-term versus long-term effects, and (e) the effect after removal of the device, or speed choice behavior in situations in which the system is turned off or does not work.

We found that there is not much uncertainty regarding the effect of ISA on speed choice behavior. All research we found indicates that ISA reduces speeding and inappropriate speed choice behavior, resulting in large reductions in accidents and accident outcomes. Carsten and Tate (2005) estimate that, depending on the type of ISA, the reduction in fatal accidents can be as high as 59%. More recent calculations by Carsten et al. (2008) show that, depending on the implementation strategy a reduction in fatal accidents of 42% by 2045 can be achieved in the UK. Uncertainty regarding the effects of different ISA types on speed choice behavior has also been addressed in different publications. In general, it can be concluded that the more permissive the ISA, the less effect on speed choice behavior (Adell and Varhelyi, 2008; Comte and Jamson, 2000). Basically, the direction of the effect is known, but the magnitude remains uncertain.

The results with respect to the impact of ISA on speed choice behavior are mixed and, thus, uncertain. For instance, some research concludes that ISA was most effective in reducing the time spent speeding, free flow speed, and mileage spent speeding in 90 km/h zones or rural roads (e.g. Vlassenroot et al., 2007; Agerholm et al., 2008a). On the other hand, trials in the Netherlands, Sweden, and Spain indicate just the opposite. ISA reduced the mean speed on urban roads (30–60 km/h), but for the rural roads (80–90 km/h) the reduction was not significant. The difference in results is assumed to be caused by the traffic situations in these specific cases (Varhelyi and Måkinen, 2001). ISA has also proven to be very effective in eliminating momentarily high speeds (Varhelyi et al., 1998; Varhelyi and Måkinen, 2001). Comte (2000) found a decrease of mean speed at specific risk locations. Overall, ISA is very effective in reducing negative speeding behavior; in situations in which speed is already low (due to traffic conditions), results turn out to be insignificant.

Research by Adell et al. (2008) shows that ISA only has an effect when it is turned on, not merely by its presence. This research showed that, when ISA was assumed to be turned off, people immediately returned to their old speed choice behavior. This seems to be contradictory to the research by Varhelyi et al. (2004), which indicated no compensatory behavior in situations in which the ISA did not work. Moreover, no compensatory behavior in terms of speeding at intersections or higher turn speeds. Another uncertainty that was researched was the effect of ISA related to different types of drivers. However, the results of these studies show differences, and the effect of ISA on the various driver types is still uncertain, and varies depending on the scope of the research. Danish research (Agerholm et al., 2008b) shows positive effects of ISA on the speed choice behavior of young drivers, who are known to be most likely to speed. A reverse effect was found by Vlassenroot et al. (2007). They conclude that ISA leads to higher mean speed for those drivers who are less frequent speeders. Furthermore, research indicates a decrease in the effect of ISA on speed choice behavior both for the Active Accelerator Pedal (AAP) (Hjalmalh et al., 2002; Varhelyi et al., 2004; Vlassenroot et al., 2007) and for the audio visual warning ISA types (Warner and Aberg, 2008).

Research by Adell et al. (2008) shows that ISA only has an effect when it is turned on, not merely by its presence. This research showed that, when ISA was assumed to be turned off, people immediately returned to their old speed choice behavior. This seems to be contradictory to the research by Varhelyi et al. (2004), which indicated no compensatory behavior in situations in which the ISA did not work. Moreover, no compensatory behavior in terms of speeding at intersections or higher turning speeds has been found, and test drivers with ISA showed a smoother approach speed to roundabouts and intersections (Varhelyi and Måkinen, 2001; Varhelyi et al., 1998).

The effects of ISA on other driver-related tasks have also been investigated. Uncertainty regarding the effects of ISA on car-following behavior has been researched extensively. Most research has indicated that ISA reduces the vehicle following gap (Persson et al., 1993; Comte, 2000), which leads to closer car following behavior. Varhelyi and Måkinen (2001) conclude that safer car following behavior occurred on urban roads (30–50 km/h). However, on 70–90 km/h roads, the tendency was the opposite – vehicle gaps decreased (meaning riskier car following behavior).

To conclude, the effect of ISA on driver behavior remains uncertain. There are indications of what can happen, but the size of the effects remain uncertain. Here we can also add that comparing the different behavioral studies is difficult – even more so when it comes to long-term effects (Saad, 2006). Moreover, the long-term effects and the effects of large scale implementation are unknown, and the uncertainty is compounded when it is considered in relation to the implementation strategy.

No specific research has been done into uncertainty regarding the effect of ISA users on the speed choice behavior of non-ISA using road users. However, trials in Umeå (Sweden) showed ISA has a positive effect on surrounding traffic (Biding and Lind, 2002). Since the implementation of ISA will likely not happen in one day, the effects of ISA in mixed traffic are important to know, but remain uncertain.

3.1.2.2. Uncertainty regarding the effect of ISA on driver behavior that is not speed choice related. Varhelyi et al. (2004) found no evidence that the behavior of ISA drivers towards other road users improved. The assumed effect of ISA on ‘give-way’ behavior varies. Early research by Persson et al. (1993) indicated a slight increase in incorrect ‘give-way’ behavior at intersections. Others found no negative effects (Varhelyi et al., 1998; Varhelyi et al., 2004) or even a slightly positive effect (Almqvist and Nygard, 1997, found in Varhelyi et al., 1998). Furthermore, research has concluded that ISA does not change overtaking behavior (Comte, 2000; Varhelyi and Måkinen, 2001; Adell et al., 2011) and causes no loss in vigilance (Comte, 2000). Another driving task that belongs to this category, and that takes place at a strategic level is route choice (Michon, 1985). No research has been found that addresses the effect of ISA on route choice, so this remains uncertain.

3.1.2.3. Uncertainty regarding the effects of ISA on travel time and congestion. Different trials of ISA have indicated an increase in travel time. In 1998, Varhelyi et al. concluded that the travel time increase due to ISA was 2.5–2.8%, depending on the country (Netherlands, Spain, or Sweden). Similar effects on travel time were reported by Varhelyi and Måkinen (2001) and by Liu and Tate (2004). Broekx and Panis (2004) found a small effect, and no effect on travel times was reported by Varhelyi et al. (2004). The differences in these research results might be explained by the fact that Varhelyi et al. (2004) analyzed the effects of ISA in a network in which speeds were already very low. Despite the increase in travel times, microsimula-
tion has shown that ISA does not lead to increased traffic jams (Liu and Tate, 2004). In this specific case, the result is due to the fact that during peak times, when traffic jams occur, most of the vehicles are already moving below the speed limit, so ISA will not lead to additional traffic jams. To conclude, the effect of ISA on travel time seems to be negative; the size of the effect seems to be small. There is still a large uncertainty when it comes to the effects of the size of the effect for large-scale penetration of ISA.

3.1.2.4. Uncertainty regarding the effects of ISA on driver workload and comfort. Most research indicates that ISA results in reduced driver comfort. Värhelyi and Mäkinen (2001) report that drivers feel an increased frustration. After trials in the Netherlands, Broekhuis and De Waard (1997, 1999) indicate a slight increase in mental workload based on self-reporting (no increase could be measured using heart monitoring). Rook and Hogema (2005) looked at the effects of different levels of ISA feedback force (for haptic throttle) on frustration level and workload. They found that a high feedback force leads to more workload and frustration than a low feedback force. However, the workload of driving with the Restricting ISA and with a vibrating pedal does not lead to more workload than driving without ISA. This is in line with other results that indicate that the more intervening ISA is, the less likely it is perceived to be acceptable (see e.g. Comte and Jamson, 2000). Comte and Jamson (2000) found no differences in workload between Advising and Restricting ISA. They also showed that providing the drivers with speed limit information does not necessarily result in a higher workload. To conclude, it seems to be certain that drivers perceive more intervening types of ISA as frustrating (the effect of long-term usage and perfectly working ISA is uncertain). Furthermore, there seems to be little uncertainty about the effect of ISA on workload (no effect or very small effect).

3.1.2.5. Uncertainty regarding the effects of ISA on emissions and fuel use. A number of studies have looked into the effects of ISA on both fuel use and emissions. Almost all conclude that ISA has a positive effect on fuel use and emissions. Värhelyi et al. (2004) find significant reductions in CO₂ and NOₓ emissions. Broekx and Panis (2004) mention a reduction in CO₂ and NOₓ emissions, together with a decrease in HC and PM emissions. Broekx and Panis (2004) also mention a reduction in fuel use of 2% (between 0.8% and 3.2%, depending on the type of road). Liu and Tate (2004) studied ISA effects on network efficiency, fuel consumption, and emissions through detailed microsimulations. Assessing an ISA penetration level of 100%, they found fuel savings of 8% for urban peak, 8% for urban off-peak, 3% for rural roads, and 1% for motorways. The results for emissions were mixed. They found that the emissions of CO, NOx, and hydrocarbons varied by only ±2% for all ISA penetration rates (see also Carsten and Tate, 2005). To conclude, it is fairly certain that ISA will have an effect on fuel use and emissions, and that this effect will be positive; however, the size of the effect is uncertain.

3.1.2.6. Uncertainty regarding the legal aspects of ISA implementation. Legal aspects are often mentioned as a barrier for ISA implementation (e.g. Marchau et al., 2002; Värhelyi et al., 2004; Argioul et al., 2006; Goodwin et al., 2006). In general, it is argued that those ISA systems that do not intervene more with the driving task than already available systems on the market (e.g. ABB, TC, and ESP) will not encounter product liability problems (Goodwin et al., 2006; Albrecht, 2005). However, intervening ISA products need to be approved and tested by an approved testing organization before they can be implemented, since it is an offense to modify a vehicle’s braking system (Jamson et al., 2006). In addition, in case of intervening ISA malfunctioning, the user can claim that the accident was not caused by the driver but by a technical defect. Such a defense has a high likelihood of succeeding (Van Wees, 2004). To conclude, research indicates that the more intervening a system is the more legal constraints become an issue. Liability issues do not seem to be a barrier for Warning ISA. However, the situation is not completely clear for Assisting ISA. In general, it is assumed that the driver still is responsible for his or her driving, since the system does not interfere with the driving task more than other already implemented systems. Restricting ISA seems to be impossible without legislative changes. Furthermore, there also seems to be a relationship between the legal aspects and the implementation strategy.

3.1.3. Uncertainty regarding the system’s response to external forces and policies – parameter values

Several uncertainties regarding parameter values of system models have been addressed in previous research. In the case of overridable ISA, an important issue for modeling the effects is uncertainty regarding the level of compliance with the ISA system. Research shows that voluntary ISA is likely to be overruled in many cases, depending on a variety of factors (e.g. road and driver characteristics, familiarity with the ISA system, etc.) (Carsten et al., 2008; Jamson, 2006; Comte, 1999). Carsten and Tate (2000) indicate that, based upon trials, they estimate the level of compliance to be 50%. To conclude, there is very limited knowledge regarding the levels of compliance with overridable systems that can be expected when ISA is implemented, hence this is still uncertain.

Another uncertainty in modeling the effects of ISA is the level of penetration that is to be expected when ISA is implemented. Carsten et al. (2008) developed four implementation scenarios that are combinations of type of ISA system and whether adoption is mandatory (government driven) or voluntary (market driven). These implementation scenarios resulted in different penetration levels for different systems in different years. The effect of different penetration levels of ISA-equipped vehicles has been assessed by microsimulation (Xiaoiliang et al., 2004; Xiaoiliang and Andreasson, 2005; Wang et al., 2007). The results indicate that different ISA penetration levels will have different effects on speed (low penetration levels result in speed waves and higher penetration level result in more stable speeds). Given the very specific focus of the research done (mainly focused on the UK), and the limited number of studies regarding the subject, the effect of ISA implementation policies on penetration rates is considered to be uncertain.

3.1.4. Uncertainty regarding the current valuation of outcomes

Research that addresses the way stakeholders value ISA is mainly focused on potential ISA users and drivers in general, often differentiating among ISA types (e.g. Warning ISA, Restricting ISA, etc.), specific driver groups (e.g. young drivers, aggressive drivers), and road types (e.g. urban roads, 30 km/h roads, etc.). ISA research on driver acceptance defines acceptance in different ways (e.g., willingness to buy ISA, willingness to install ISA, willingness to use ISA, willingness to comply with the ISA system).

Literature review regarding the acceptance of ISA shows that the more intervening the system is the less people are willing to accept it (e.g. Comte and Jamson, 2000; Garvill et al., 2003; Rook and Hogema, 2005). Different groups of drivers are distinguished. Jamson (2006) concludes that those drivers that are most inclined to exhibit speeding behavior are least likely to use ISA. (Garvill et al. (2003) and Rienstra and Rietveld (1996) draw similar conclusions.) Young drivers seem less inclined to accept an ISA system, and older, more experienced drivers tend to like the system (De Waard and Brookhuis, 1997; Young et al., 2004). Other researchers conclude that women are more in favor of ISA than men (Rienstra and Rietveld, 1996; Piao et al., 2005), and higher-educated people are more against electronic speed limiters (Rienstra and Rietveld, 1996). Others have looked into the factors that influence the acceptance of ISA. Marchau et al. (2005) indicate that the willingness of
drivers to adopt ISA depends on the functionality and the flexibility of the ISA system and the price (ISA should have a rather low price). Others mention technical functioning of the system (Risser, 2002). Molin and Brookhuis (2007) identify three factors that have the most effect on ISA acceptability: (1) the belief that driving too fast is a major cause of accidents, (2) the belief that ISA can contribute to attaining various personal and social goals, and (3) the extent to which one prefers a more limiting ISA. Research indicates uncertainty about whether using ISA influences its acceptance. Varhelyi (2002) and Comte (2000) report that the acceptance of ISA increases after people have tried it. However, opposite results were reported by Van Nes et al. (2008). They see a decline in acceptance after drivers use the system. They suggest that this might be due to the characteristics of the specific system they studied. It has to be noted that, in general, the research on user acceptance varied a lot among the different trials (Vlassenroot et al., 2010), and no coherent acceptance indications were described. In general, it could be said that, although the notion that the more intervening the system is the less people are willing to accept it suggests that drivers are unwilling to yield control to anything or anybody, the truth is more complex (see e.g. Vlassenroot et al., 2010). Carsten (2002) noted that the attitudinal research on acceptance of ISA could be criticized for not being sufficiently rigorous. It can be concluded that, although a lot is known about the factors that affect the level of acceptance, the extent to which the individual factors influence acceptance is uncertain. Furthermore, the effects of different implementation strategies on acceptance are unknown, as are the long-term effects of ISA usage on acceptance.

Most research has focused on the opinions of potential ISA users; little research has been done into other stakeholders’ opinions. Marchau et al. (2002) researched the actors involved in ISA implementation and their opinions of different ISA systems. Also, a stakeholder analysis was carried out as part of the PROSPER research project (PROSPER, 2004). Reviewing the stakeholder literature for ISA, Walta et al. (2006) concluded that most research has focused on the user, and that none of the studies distinguished preferences among different stakeholders. The preferences of different stakeholders towards ISA, therefore, seems to be uncertain.

3.1.5. Uncertainty regarding the future valuation of outcomes

No research was found that addressed the future valuation of outcomes by different stakeholders or the future stakeholder configuration, resulting in uncertainty regarding these subjects.

3.2. Conclusions of the literature review

The literature review resulted in three main products:

- A database containing more than 185 publications.
- An overview and synthesis of the literature regarding the outcomes of research performed in the past addressing important ISA implementation uncertainties (see rest of this section).
- A list of uncertainties regarding ISA implementation that is structured using the uncertainty framework of Fig. 1.

Policymaking for ISA requires dealing with the uncertainties surrounding ISA policy measures in a transparent and systematic way. Using the uncertainty framework presented in Section 2.1 (Fig. 1), we identified the 24 most important uncertainties surrounding ISA implementation (see Table 1). The results show that past research has focused on uncertainty regarding the system’s response to external forces and policies (model structure) and uncertainty regarding the current valuation of outcomes (ISA acceptance). Moreover, this current valuation of outcomes is focused on one type of stakeholder – the potential ISA user. Table 1 also presents an overview of all the uncertainties addressed in the literature. Several uncertainties that are relevant for ISA implementation have not been researched. These include uncertainties regarding the effect of external forces, current stakeholder valuations (other than the users’), current stakeholder configuration, future stakeholder valuation, and future stakeholder configuration.

4. Expert elicitation on the level and importance of the uncertainties

We first identified 130 authors of the papers included in the database as experts. We invited each of these authors to participate in our research, and indicated that we welcomed suggestions for more experts (not necessarily scientists). This resulted in 33 additional experts, who were screened based on their self-reported level of expertise. Seventy-five experts (46% response rate) filled in the questionnaire. Sills and Song (2002) indicate that a non-response of 80% for Web-based questionnaires is not uncommon. Our response rate is, therefore, quite high. Experts were asked to answer only questions within their area of expertise. The response per question varied between 30 and 36%. The questionnaire consisted of 55 questions about 24 uncertainties. (The uncertainties are listed in Table 1.) The average time it took to fill in the questionnaire was 36 min.

To have an indication of the expertise of the experts, we asked them to report their current occupation and their area of expertise. A large majority of the experts were university researchers (55%). They represented a very diverse set of areas of expertise (e.g. control theory, transport innovations research, behavioral sciences). The other occupations represented among the experts were: public policymaking (11%), consultancy (16%), automotive industry (4%), and other (14%).

We also asked the experts to indicated their expertise per subject. The subjects were created based upon the uncertainties that resulted from the literature review. The majority of the experts represented themselves as experts (ranging from minor to major). Medium to major expertise was indicated by the majority of respondents for almost all subjects, except for the external factors that influence ISA implementation, implementation and liability issues, and stakeholder opinion and stakeholder configuration issues. Although the experts said that they had little expertise on these subjects, in all cases the expertise that they reported was considered dominantly minor instead of none. All in all, these data indicated that our experts had a sufficient level of expertise to support our research.

Section 4.1 discusses the results concerning the experts’ opinions on the levels of the various uncertainties. Section 4.2 discusses their opinions on the importance of the uncertainties. Section 4.3 presents several uncertainties added to the original list by the experts.

4.1. Results on the level of uncertainty

Table 2, shows, for the three types of ISA (Warning, Assisting, and Restricting), the uncertainties whose uncertainty levels ranked the highest (top 5), based on their mean uncertainty scores. The levels of uncertainty were scored on a 1 to 5 scale (where 1 corresponds to ‘fully determined’ and 5 corresponds to ‘fully uncertain’).

As can be seen in Table 2, the largest uncertainties surrounding the implementation of ISA all apply to Restricting ISA, although the differences with Assisting ISA are small. Furthermore, the ranking of level of uncertainty seems very consistent across the different types of ISA – there are only six uncertainties in the top 5 across the three systems. This indicates that these uncertainties are perceived to be relatively equally uncertain across the types of ISA systems. Most uncertain are the liability allocation aspects in case of a malfunctioning ISA and uncertainties related to behavioral adaptation of
Table 1
Most important ISA uncertainties derived from the uncertainty framework and literature.

<table>
<thead>
<tr>
<th>Uncertainty category</th>
<th>#</th>
<th>Uncertainty regarding</th>
</tr>
</thead>
<tbody>
<tr>
<td>The relevance and values of relevant external forces</td>
<td>1</td>
<td>Effect of external developments on the implementation of ISA. (E.g. uncertainties may exist regarding the effect of economic developments, effect of technological developments, effect of demographic developments, etc.)</td>
</tr>
<tr>
<td>Uncertainty regarding the system’s response to external forces and policies – model structure</td>
<td>2</td>
<td>Effect of ISA on the speed choice behavior of ISA users</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Effect of long-term ISA use (over 2 years) on ISA users</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Effect of ISA on travel behavior (route choice behavior, mode choice behavior, etc.)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Effect of ISA on fuel use and environmental pollution</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>The cost of ISA implementation</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Effect of ISA implementation on accident and accident outcomes</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Effect of ISA on the transport network (e.g. network capacity, network efficiency, network throughput, etc.)</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Effect of ISA on driver workload</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Effect of ISA on driving comfort</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Behavioral adaptation of drivers that use ISA (e.g. delegation of responsibilities, less vigilance driving)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Behavioral adaptation of other road users</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Effect of ISA on other (not speed choice related) drive-task related behavior of ISA users (e.g. car following behavior, give way’ behavior, overtaking behavior)</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>The size and nature of the effect of compensatory behavior of ISA users (e.g. speeding when system is not engaged, more aggressive and rapid acceleration)</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Technical reliability of ISA and the effects of a malfunctioning ISA</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>Technical characteristics and updating of the speed limit database (e.g. what is the best speed limit database format, what is the best way to update the speed limit database, etc.)</td>
</tr>
<tr>
<td>Uncertainty regarding the system’s response to external forces and policies – parameter values</td>
<td>17</td>
<td>Liability allocation in case things go wrong with the functioning of ISA (liability issues)</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Effect of different penetration levels. (E.g. what will be effect of ISA when over 80% of the vehicle fleet is equipped? Or what will be the effect of ISA when 30% of all vehicles are equipped?)</td>
</tr>
<tr>
<td>Uncertainty regarding the stakeholder configuration</td>
<td>19</td>
<td>Effect of different ISA implementation strategies on ISA implementation (e.g. voluntary implementation, giving incentives, mandatory implementation)</td>
</tr>
<tr>
<td>Uncertainty regarding the current valuation of the outcomes of ISA implementation</td>
<td>20</td>
<td>Which stakeholders are involved in implementing ISA and the importance of each of the stakeholders for ISA implementation</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>The amount of money people are willing to pay for ISA</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>Factors that contribute to ISA acceptance of car drivers, and the degree to which each of these factors contributes to the level of acceptance (e.g. driver characteristics, road conditions, level of intervention)</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>Willingness of people to use ISA (E.g. in which situations are people willing to use ISA? What is the relationship between the way ISA is implemented (voluntary, mandatory) and the willingness use ISA? etc.)</td>
</tr>
<tr>
<td>Uncertainty about the future stakeholder configuration</td>
<td>24</td>
<td>Dynamics of stakeholder configuration (e.g. who are the future stakeholders, how important will they be)</td>
</tr>
</tbody>
</table>

Uncertainty about the future valuation of the outcomes of ISA implementation

other road users (non-ISA drivers). (Most experts labeled the latter uncertainty as ‘recognized ignorance’.) This is consistent with the results of the literature review, which found little research regarding the behavioral adaptation of other road users and found that uncertainty regarding liability issues was still uncertain for more restricting types of ISA especially when considered in combination with the implementation strategy (see Section 3). Uncertainty regarding behavioral adaptation of other road users is indicated to

Table 2
Uncertainties with the highest levels of uncertainty, per ISA type.

<table>
<thead>
<tr>
<th>#a</th>
<th>Uncertainty</th>
<th>Warning Rank</th>
<th>Mean</th>
<th>σb</th>
<th>Assisting Rank</th>
<th>Mean</th>
<th>σb</th>
<th>Restricting Rank</th>
<th>Mean</th>
<th>σb</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Uncertainty regarding behavioral adaptation of other road users</td>
<td>1</td>
<td>3.15</td>
<td>1.26</td>
<td>2</td>
<td>3.34</td>
<td>1.16</td>
<td>2</td>
<td>3.50</td>
<td>1.11</td>
</tr>
<tr>
<td>22</td>
<td>Uncertainty regarding the liability allocation in case things go wrong</td>
<td>2</td>
<td>3.11</td>
<td>1.12</td>
<td>1</td>
<td>3.45</td>
<td>1.02</td>
<td>1</td>
<td>3.61</td>
<td>0.97</td>
</tr>
<tr>
<td>4</td>
<td>Uncertainty regarding the effect of ISA on travel behavior</td>
<td>3</td>
<td>2.88</td>
<td>1.32</td>
<td>5</td>
<td>3.16</td>
<td>1.20</td>
<td>3</td>
<td>3.40</td>
<td>1.12</td>
</tr>
<tr>
<td>12</td>
<td>Uncertainty regarding behavioral adaptation of drivers that use ISA</td>
<td>4</td>
<td>2.87</td>
<td>1.02</td>
<td>3</td>
<td>3.19</td>
<td>1.00</td>
<td>6</td>
<td>3.29</td>
<td>0.97</td>
</tr>
<tr>
<td>17</td>
<td>Uncertainty regarding the effect of different ISA implementation strategies</td>
<td>5</td>
<td>2.80</td>
<td>1.00</td>
<td>4</td>
<td>3.18</td>
<td>0.96</td>
<td>4</td>
<td>3.36</td>
<td>0.91</td>
</tr>
<tr>
<td>24</td>
<td>Uncertainty regarding the dynamics in stakeholder configuration</td>
<td>8</td>
<td>2.74</td>
<td>1.21</td>
<td>6</td>
<td>3.14</td>
<td>1.02</td>
<td>5</td>
<td>3.36</td>
<td>0.99</td>
</tr>
</tbody>
</table>

a Corresponding uncertainty number in Table 1 and Appendix A.
b Standard deviation.
be very uncertain (mostly rated as ‘recognized ignorance’). This is consistent with the conclusion of the literature review that little research was found into this subject (see Section 3.1.2). The same can be concluded for the effects of ISA on travel behavior (e.g. mode choice and route choice, which are discussed in Section 3.1.2).

Uncertainty regarding behavioral adaptation of drivers that use ISA was indicated to be a scenario uncertainty. This is consistent with research performed in the past (see Section 3.1.2). Based upon past research, we are aware of the things that can happen, but which situation will occur remains uncertain – hence, scenario uncertainty.

Uncertainty regarding the effect of different ISA implementation strategies is indicated to be very high (most experts rated this to be a scenario uncertainty for Warning and Assisting ISA and recognized ignorance for Restricting ISA). This uncertainty was further specified in the open questions by different experts, who indicated that this uncertainty mainly reflects uncertainty regarding the effect of different implementation strategies on the acceptance of ISA (in terms of willingness to use and to buy), and, related to that, the uncertainty regarding what the preferred strategy is when it comes to implementing the different types of ISA.

As indicated in the literature review in Section 3.1.5, uncertainty regarding the dynamics in stakeholder configuration has not been significantly addressed in literature and research. Despite the fact that it has not been researched in the past, the experts indicated that they consider this to be a scenario uncertainty (for the Assisting and the Restricting ISA). An explanation for this could be that the experts have a good idea of the stakeholders involved in ISA implementation and the stakeholders that could be involved in ISA implementation, and they do not see any unexpected changes in the future stakeholder configuration.

Regarding the level of uncertainty, the experts added that there are synergy effects regarding the uncertainty and the overall level of uncertainty that are relevant for decision making. These interactions lead to complex issues and additional uncertainty.

4.2. Results on the importance of the uncertainties

Table 3 shows, for the three types of ISA (Warning, Assisting, and Restricting), the uncertainties whose barrier scores ranked the highest (top 5). Based on their mean levels of importance. The levels of uncertainty were scored on a 1 to 4 scale (where 1 corresponds to ‘no barrier’, 2 corresponds to ‘minor barrier’, 3 corresponds to ‘medium barrier’ and 4 corresponds to ‘major barrier’).

For Warning ISA, there seems to be almost no significant barrier left for implementation. The only barrier rated to be between minor and medium is related to the in-vehicle speed limit database characteristics and maintenance. The experts indicate that this is one of the only remaining major technical and organizational challenges left when it comes to implementation. With respect to the speed limit database, there are a number of barriers that are mentioned by the experts: first, the organizational aspects of the development of a speed limit map/database and the accuracy of this speed limit map (who should do this, to what extent is the developer responsible for accuracy, etc.). Second, there is the technical challenge of developing a speed limit database, and even more challenging, the issue of updating the database. Finally, experts indicate that there is no single straightforward standard regarding the technical specification of speed limit databases, and there is a lack of effort to standardize the speed limit database. It is clear that the more intervening the system is, the more this uncertainty becomes a barrier for implementation.

For the more intervening types of ISA (Assisting and Restricting), uncertainties surrounding the liability issues are considered to be the most important barrier for implementation (most experts indicated this as a medium uncertainty for Assisting ISA and a major barrier for Restricting ISA). This is in line with the literature (see Section 3.1.2). It also indicates that the institutional settings (e.g. legislation) make it more difficult to implement the more restricting types of ISA.

Uncertainties regarding acceptance were indicated to be an important barrier. This is clearly indicated in Table 3, which shows that uncertainty regarding the willingness to use ISA and uncertainty regarding the factors that influence acceptance are considered to be barriers. This was further mentioned in the open questions, where the experts indicated that the lack of knowledge on the willingness to use and install ISA is an important barrier (e.g., the experts said that willingness to use depends on traffic scenarios, driver characteristics, and implementation measures, and on long-term and large-scale usage).
Uncertainty regarding the effect of different implementation strategies was considered to be an important barrier. The experts further specified this barrier in the open question regarding barriers for implementation. They indicated that not only is the uncertainty regarding the effect of different implementation strategies on the level of penetration uncertain, but also uncertain is the effect of the strategy on the usage of ISA (e.g. will mandatory implementation of an advisory ISA lead to more overruling of the system?).

The effect of large-scale implementation seems to be very uncertain (e.g. the effects on traffic safety, effects on throughput, etc.). Some of the experts indicated that stakeholders do not want to take the lead in implementation because the effects of large-scale real world implementation of ISA are unknown. On the other hand, the experts also indicated that, in order to make a difference, ISA implementation must reach a certain level of penetration. This is needed both to facilitate further large scale implementation (maturing of technology, people learn about the system) and to harvest safety effects.

Finally, for Restricting and Assisting ISA, a number of additional uncertainties were indicated to be medium to important barriers by most experts. For both Restricting and Assisting ISA, the cost of ISA implementation is a barrier. This can be explained by the fact that experts expect these types of ISA to be required based on public policy. Also indicated to be important barriers are the effects of Assisting ISA and Restricting ISA on the non-speed related behavior of ISA users and the counteractive behavior of ISA users. The unknown effect of external developments on the implementation of Restricting ISA is seen as an important barrier for the implementation of Restricting ISA. The willingness to pay for ISA is also an important barrier for implementation of both Assisting and Restricting ISA. With respect to this barrier, the experts indicated that none of the stakeholders seems to be prepared to pay for a system that limits the freedom of the user.

Table 3 shows that the more intervening the ISA, the more uncertainty is considered to be a barrier for implementation. However, the magnitude of this relationship differs among the uncertainties. To see which relationships are significant, we tested the relationships in paired sample t-tests.

For most of the uncertainties the relationship between the extent to which an uncertainty is a barrier and the level of intervention proves significant. This is consistent with the notion that the more an ISA is intervening the longer it will take before it is implemented. This is also consistent with the fact that warning devices are currently being implemented (e.g. on navigational devices), and initiatives are being deployed for Assisting ISA to be implemented (e.g. like in London). This is also the likely reason why all the uncertainties mentioned were significantly more a barrier for Warning ISA than for Assisting ISA. However, for six of the 24 uncertainties, the mean values did not differ significantly between the Assisting and Warning variants, which means that, for these cases, this relationship may not exist. These six uncertainties are:

- #2 – uncertainty regarding the effect of ISA on the speed choice behavior of ISA users
- #3 – uncertainty regarding the effect of long-term ISA use on the ISA users
- #5 – uncertainty regarding the effect on fuel use and environmental pollution
- #7 – uncertainty regarding the effect of ISA implementation on accidents and accident outcomes
- #8 – uncertainty regarding the effect of ISA on the transport network
- #9 – uncertainty regarding the effect of IS on driver workload

These six uncertainties appear to be minor barriers for both Assisting and Restricting ISA.

4.3. Results on additional uncertainties regarding ISA implementation

Overall, the experts indicated that the list of uncertainties is quite complete. However, some experts added a few uncertainties. Three items were (frequently) added by the experts: (1) uncertainty regarding the long-term effects of ISA implementation (e.g. how will long-term usage of ISA affect user and non-user behavior, and what will be the overall effects on the transport system); (2) uncertainty regarding the effect of large-scale real world implementation of ISA (e.g. what will happen with capacity if the majority of all vehicles are equipped with ISA); and (3) there are synergy effects among the uncertainties. Several experts indicated that each of the uncertainties in itself is not a major barrier, but that the sum total of the uncertainties served as a major barrier to ISA implementation. Uncertainties that were also mentioned more than once, are:

- uncertainties regarding political issues (effects of lobbyists on politicians, political will to take a decision, how can ISA implementation be put on the political agenda?).
- uncertainties regarding how ISA implementation would perform as a policy option as compared to other policy options (E.g., would limiting the maximum speeds of cars by design not be more efficient/effective?)

Uncertainties that were included in the survey but which the experts elaborated on further were:

- uncertainties regarding acceptance issues (e.g., how will drivers feel if they are just one of the few ISA drivers on the road?, in what situations are drivers willing to use ISA? and marketing issues, such as how can we “sell” ISA to the users?).
- uncertainties regarding the design and maintenance of the speed limit database.

5. What remains to be done?

The final sub-question that is discussed is: what are the most important research needs, from the perspective of facilitating the implementation of ISA? Based upon the literature review, we conclude that, although a lot of research has been done, large uncertainties regarding ISA still remain. These uncertainties still exist for one of two reasons: (1) because past research did not address the subject (e.g. subjects like future valuation of outcomes), or (2) past research did not result in unambiguous results (e.g. like the effect of ISA on the behavior of ISA users towards other road users). Looking at the results of the literature review and the expert opinions, we conclude that the uncertainties regarding ISA fall into three categories, based on the way in which to deal with them:

- Uncertainties that can be dealt with by doing more research (reduce the uncertainty)
- Uncertainties that can be dealt with in an organizational manner (taking leadership and developing policies)
- Uncertainties that can only be dealt with by implementation and subsequent observation
Note that none of these uncertainties will be completely resolved until implementation takes place (e.g. uncertainties regarding ISA implementation; in the real world, on the long-term and on a large scale) and, for the uncertainties related to the long-term effects, the ISA needs to be implemented for a longer period. Appendix A presents graphs for the three types of ISA indicating how interesting the uncertainties are for ISA implementation. The higher the level of uncertainty and the more the uncertainty is a barrier for implementation, the more research is still needed.

The graph for Warning ISA shows that there are a large number of uncertainties left, but none of these is a significant barrier for implementation. From the fact that warning types of ISA are currently being implemented, we can conclude that, although experts indicate that there is still uncertainty left, and these are minor barriers for implementation, this is not blocking ISA implementation. However, implementation could be sped up by standardization of speed limit databases and incentives for buying and using warning types of ISA (see for instance the activities by the city of London and the Dutch Ministry of Transport, Public works and Water management\(^3\)). Important in this case is also ex-post evaluation of the implementation of Warning ISA. This could result in important information that can be used when implementing more Restricting types of ISA.

The graphs in Appendix A show that the implementation of Assisting ISA and Restricting ISA present more of a challenge. In general, there are more serious barriers to implementation, and the overall levels of uncertainty are higher. The results from the literature review and the expert elicitation study suggest that three types of actions can be recommended to facilitate their implementation: additional research, more organizational changes, and beginning implementation (perhaps on a small scale). Based upon the literature and expert opinion, Table 4 shows the category of action that is most appropriate for each of the uncertainties that were indicated to be medium or major barriers by most of the experts or that were mentioned multiple times in the open questions.

The first column of Table 4 shows the research needs for Assisting and Restricting ISA from the perspective of facilitating the implementation of ISA. This column shows that, because Assisting and Restricting ISA are assumed not to be able to be implemented without policy intervention (this was indicated by the experts), it is important to know what the effect of different strategies will be on implementation (mainly on acceptance), but also who are and who will be involved in future implementation (what are their preferences, goals, and opinions, and how will these evolve over time). For Restricting ISA, fundamental research is still needed on the effects of ISA on driver behavior.

The second column in Table 4 shows the organizational needs for Assisting and Restricting ISA that would facilitate the implementation of ISA. Uncertainty regarding the technical characteristics of the speed database and the updating of the speed database can best be addressed in an organizational manner. Experts indicated that this is more a matter of standardization and some product development. Hence, this is more an organizational challenge than a technical one. Also, liability issues are considered to be an important barrier for ISA implementation. Research shows that this is mainly an organizational problem that can relatively easily be solved by institutional changes (legal changes) and agreements.

As shown in the third column of Table 4, the uncertainty about liability issues can only really be resolved by implementing ISA and seeing what happens in the courts. Uncertainty regarding large-scale implementation, real world implementation, long-term effects, and the synergy effects of all the uncertainties can also best be dealt with by starting to implement ISA.

The question is: how can we start implementing ISA despite all these uncertainties? Recently, policymaking approaches that can facilitate ISA implementation despite the remaining uncertainties have been developed. An approach that facilitates dealing with the three categories of actions in an integrated manner is the Adaptive Policymaking (AP) approach of Walker et al. (2001). AP allows implementation to start on a small scale to learn the effects of small scale ISA implementation over time. It is also able to incorporate research and organizational aspects, in the form of mitigating and hedging actions. As such, AP is one way to deal with the above mentioned uncertainties. (See Agusdinata et al. (2007) for an example of how AP can be applied to the problem of implementing ISA.) Two other benefits of using AP are (1) stakeholders are actively involved, which allows policymakers to deal with the important acceptance issues surrounding ISA implementation, and (2) actions take place in parallel and not sequentially (which means implementation can start today and not after additional research is done).

---

Other related approaches for facilitating ISA implementation in the face of its many uncertainties are strategic niche management (Rotmans, 2003) and Robust Decision Making (Dewar et al., 1993; Lempert et al., 2003).

6. Conclusions and recommendations

In this section, we first answer the four sub-questions asked in the introduction.

6.1. What uncertainties are associated with ISA implementation?

The literature review resulted in 24 uncertainties that still surround ISA implementation, which were confirmed by experts (see Table 1). Furthermore, there appear to be uncertainties regarding the large-scale real-world implementation (e.g. what will be the effect of large scale implementation on the level of acceptance, traffic safety and network capacity) of ISA and uncertainties regarding the long-term effects of ISA. Less mentioned but also added were uncertainties about political issues surrounding ISA implementation (e.g. effects of lobbyists on politicians, political will to take a decision).

6.2. What is the level of each of the uncertainties?

Overall, most of the uncertainties are indicated to be scenario uncertainties (i.e., how the main mechanisms work is understood, the range of things that can happen is known, but their likelihood is unknown). Issues that are still very uncertain are: the behavioral adaptation of ISA drivers and of other road users than ISA drivers, the effect of ISA on travel behavior, the effects of different implementation strategies, and the dynamics in the stakeholder configuration. Experts also mentioned that there are large uncertainties regarding the long-term effects of ISA, the effects of a large-scale real-world implementation of ISA, and the synergy effects of all the uncertainties taken together.

6.3. How important is each uncertainty as a barrier for implementing ISA?

Few of the deep uncertainties identified in the previous step obstruct the implementation of Warning ISA. In fact, Warning ISA is already available on some navigational devices. An interesting result is that the uncertainties that were considered to be important barriers for Assisting and Restricting ISA were generally not evaluated as the most uncertain. The experts felt that the most important barriers to implementing Assisting and Restricting ISA are: uncertainty regarding liability, uncertainty regarding acceptance (willingness to use, willingness to buy, factors that contribute to acceptance), uncertainty regarding the effects of different implementation strategies, and uncertainty regarding different stakeholders and their importance.

6.4. What are the most important research needs, from the perspective of facilitating the implementation of ISA?

Since Warning ISA is already being implemented, the most important research needs for Warning ISA should be focused on speeding up ISA implementation. Governments can help by taking action to supply speed limit information and standardizing speed limit databases (which is also important for other types of ISA).

For Assisting and Restricting ISA, we identified the most important research needs based upon both the extent to which an uncertainty was indicated to be a barrier and its level of uncertainty. Fundamental research is needed into:

- the effect of external developments on the implementation of ISA
- behavioral adaptation of drivers that use ISA (counteractive behavior)
- the effect of ISA on other (not speed choice related) drive-task related behavior of ISA users
- the effect of different ISA implementation strategies on ISA implementation (effect on acceptance issues)
- which stakeholders are involved in implementing ISA and the importance of each for ISA implementation
- stakeholder dynamics

To effectively deal with barriers regarding the speed limit database, cost of implementation, malfunctioning of ISA, and liability issues, organizational effort is required and not necessarily more research. On an organizational level, parties have to agree (upon standards), make agreements (on the cost of implementation), and make decisions (legislative changes and implementation decisions). Uncertainties about long-term effects, large-scale implementation effects, and synergy effects can be dealt with only by starting implementation and monitoring the results. This could, for instance, start with the notion that the implementation of Warning ISA is hampered least by uncertainty, and is already being implemented on a voluntary basis. So, an interesting way to move forward would be a phased implementation (moving from Warning ISA to Restricting ISA). Given the urgency of the road safety problem, it would be better to begin implementation of ISA today rather than tomorrow, which can be facilitated through the use of adaptive policies (see e.g. Walker et al. (2003) and Agusdinata et al. (2007)).

Acknowledgments

The authors thank the Next Generation Infrastructure Foundation, which supported this research.

The authors also thank two anonymous reviewers for their useful comments on an earlier version of this paper.

Appendix A. Level of uncertainty versus barrier for implementation, for three types of ISA.
**Uncertainty labels used in figures**

1. Uncertainty regarding the effect of external developments on the implementation of ISA
2. Uncertainty regarding the effect of ISA on the speed choice behavior of ISA users
3. Uncertainty regarding the effect of long-term ISA use (over 2 years) on the ISA users
4. Uncertainty regarding the effect of ISA on travel behavior
5. Uncertainty regarding the effect of ISA on fuel use and environmental pollution
6. Uncertainty regarding the cost of ISA implementation
7. Uncertainty regarding the effect of ISA implementation on accident and accident outcomes
8. Uncertainty regarding the effect of ISA on the transport network
9. Uncertainty regarding the effect of ISA on driver workload
10. Uncertainty regarding the effect of ISA on the driving comfort
11. Uncertainty regarding the effect of different penetration levels
12. Uncertainty regarding behavioral adaptation of drivers that use ISA
13. Uncertainty regarding behavioral adaptation of other road users
14. Uncertainty regarding the effect of ISA on other (not speed choice related) drive-task related behavior of ISA users
15. Uncertainty regarding the size and nature of the effect of compensatory behavior of ISA users
16. Uncertainty regarding the technical reliability of ISA and the effects of a malfunctioning ISA
17. Uncertainty regarding the effect of different ISA implementation strategies on ISA implementation
18. Uncertainty regarding the technical characteristics and updating of the speed limit database.
19. Uncertainty regarding the willingness of people to use ISA
20. Uncertainty regarding the factors which contribute to ISA acceptance of car drivers and the degree to which each of these factors contribute to the level of acceptance
21. Uncertainty regarding the amount of money people are willing to pay for ISA
22. Uncertainty regarding the liability allocation in case things go wrong with the functioning of ISA
23. Uncertainty regarding which stakeholders are involved in implementing ISA and the importance of each of the stakeholders for ISA implementation.
24. Uncertainty regarding the dynamics in stakeholder configuration

**References**


Xiaoliang, M., Andreasson, I., 2005. Predicting the effect of various ISA penetration grades on pedestrian safety by simulation. Accident Analysis and Prevention 37 (6), 1162–1169.
