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Driver experience and acceptance of driver support systems

- a case of speed adaptation

Emeli Adell

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Keywords:
Driver experiences, acceptance, driver support systems, ISA, speed support, UTAUT, ADAS, field trial

Abstract:
Substantial research and development efforts are being made to add driver support systems to the arsenal of traffic safety measures. Obviously, the system cannot reduce fatalities and trauma until it is actually used. Hence, drivers' experiences and acceptance of the system are of paramount importance. A driver support system (ISA) has been investigated by means of real life trials in Sweden, Hungary and Spain, and the results show that the incentive for drivers to use an ISA system might be the money and embarrassment saved by avoiding speeding tickets, rather than increased traffic safety. Further, to assess the 'final', long-term experiences of the system, a longer period than one month of usage is necessary. This thesis conducts a literature review to systematically investigate how acceptance has been defined and how it has been measured within the driver support area. A new definition of acceptance is proposed: "the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving". Additionally, it explores whether the Unified Theory of Acceptance and Use of Technology model (UTAUT), which was originally developed for information technology, may be used as an acceptance model for driver support systems. A pilot test supported to some extent the use of the model. The model constructs 'performance expectancy' and 'social influence' affect drivers' intention to use the system.

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Preface

I was fortunate to be able to start my PhD-research within a unique, already ongoing experiment – the large-scale field trial with ISA (Intelligent Speed Adaptation) carried out in Lund between 1999 and 2001. My task in this project was to analyse the driver questionnaires and investigate the drivers' experience, opinions and acceptance of the system.

As the work progressed it became clear that it was not possible to determine the acceptance of the system since there was no clear definition of acceptance and the measurements used gave partly contradictory results. These experiences led to the decision to examine the concept of acceptance more thoroughly.

I consider myself lucky to have had the opportunity to be part of several important and interesting experiments and trials during my PhD-period, both in Sweden and in Europe. It is very rewarding to work in different environments, with different people and ideas. I look forward to continuing the research on the questions raised in this thesis. As my supervisor always says: the doctoral degree is the 'driving licence' for doing research on your own – there is plenty of time after the dissertation. From that perspective I am grateful for being given the opportunity to start this research and take pleasure in the thought of being able to continue with it.

I hope you, the reader, find the research interesting and the thesis enjoyable to read.

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Appended papers

List of publications

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals. The papers are appended at the end of the thesis.

Paper I Adell, E. (2007) *Drivers' evaluations of the Active Accelerator Pedal in a real-life trial,* IATSS RESEARCH. 31(1) pp. 89-99.

Paper II Adell, E. and Várhelyi, A. (2008) *Driver comprehension and acceptance of the Active Accelerator Pedal after long-term use.* Transportation Research, Part F: Traffic Psychology and Behaviour, 11(1) pp. 37-51.

My contribution: Analysis of questionnaire answers and writing of the larger part of the paper.

Paper III Adell, E., Várhelyi, A. and Hjälmdahl, M. (2008) *Auditory and haptic systems for in-car speed management – a comparative real life study,* Transportation Research Part F: Traffic Psychology and Behaviour. 11(6) pp. 445-458.

My contribution: Elaboration of questionnaires, analysis of answers and writing of the corresponding part of the paper.

Paper IV Adell, E. *On the acceptance of driver support systems.* Submitted to IET Intelligent Transport Systems

Abbreviations

AAP	Active Accelerator Pedal, an Intelligent Speed Adaptation system, mainly providing haptic feedback, for further description see chapter 2.1.1.
ABS	Anti-lock Braking System
ACAS	Automotive Collision Avoidance System
ACC	Adaptive cruise control
ADAS	Advanced Driver Assistance Systems
AVCSS	Advanced Vehicle Control and Safety systems
BEEP	An Intelligent Speed Adaptation system, mainly providing auditory feedback, for further description see chapter 2.1.2
BI	Behavioural intention to use the system
EE	Effort expectancy
ESC	Electronic Stability Control systems
FCW	Forward Collision Warning
HMI	Human Machine Interaction
ISA	Intelligent Speed Adaptation
IT	Information Technology
ITS	Intelligent Transport Systems
IVIS	In-Vehicle Information Systems
LCA	Lane Change Assist
LDW	Lane Departure Warning
NHTSA	National Highway Traffic Safety Administration
PE	Performance expectancy
PROSPER	Project for Research On Speed Adaptation Policies on European Roads, an EU-project carried out between 2003 and 2005
RDCW	Road-Departure Crash Warning System
SASPENCE	Safe Speed and Safe Distance, an EU-project, subproject to PReVENT, carried out between 2004 and 2007
SI	Social influence
TAM	Technology acceptance model
TPB	Theory of Planned Behaviour
UTAUT	Unified Theory of Acceptance and Use of Technology

1 Introduction

"While in-car safety systems have greatly improved the chances of surviving an accident, more attention now needs to be given to systems that can actually prevent accidents from happening."

Ertico (2009)

1.1 The traffic safety problem

The estimated number of road traffic fatalities worldwide is about 1.2 million each year. The number of injured could be as high as 50 million (Peden et al., 2004). Over 1 270 000 accidents resulted in personal injury and more than 42 000 people were killed (EC, 2009) in the EU in 2007, which is more than 115 lives lost a day in the EU alone and almost 3 300 lives lost globally every day. The tragedy behind these figures is unimaginable. Road traffic injuries were the eleventh leading cause of death worldwide in 2002. Road traffic was the second leading cause of death among children and young people between 5 and 29 years of age. If nothing is done, road traffic injuries are predicted to become the third leading cause of death in 2020 (Peden et al., 2004). These figures make it unnecessary to further point out the urgent need to continue to address the traffic safety problem with all available measures – both traditional and new.

The connection between accidents and driver behaviour is well established. Driver behaviour, such as speeding, driving with too short headway, drinking and driving and neglecting to use restraint systems or safety devices, has been proven to increase accident risk and/or injury severity, see e.g. Finch et al. (1994), ETSC, (2001), Najm et al. (2003), van Kampen (2003), Elvik and Vaa (2004), Nilsson (2004) and Baldock et al. (2005).

1.2 Driver support systems – potential means to improve traffic safety

Traditionally, the traffic safety problem has been tackled by means such as physical measures in the road environment, enforcement, education and passive in-vehicle safety systems. In recent years, substantial research and development has been carried out in order to add a new type of measure to the arsenal – driver support systems.

A driver support system may be defined as an in-vehicle system that collects information from the driving environment, processes it and provides information, feedback, or vehicle control to support the driver in optimal vehicle operation (van Driel, 2007). This means that these are active systems, working to prevent accidents and are not only meant to mitigate the effects when an accident is

unavoidable. Anti-lock braking systems (ABS), Electronic Stability Control systems (ESC)) and similar recovery systems are normally not included in the term "driver support systems". Besides, a variety of other terms are found in the literature, for example Advanced Driver Assistance Systems (ADAS), In-Vehicle Information Systems (IVIS) and Advanced Vehicle Control and Safety systems (AVCSS). The term 'driver support systems' has been chosen for this thesis because it refers to the most important aspect of such a system; i.e., supporting the driver in carrying out the driving task.

The extensive development work within the area of driver support systems has resulted in a range of different systems aimed at improving traffic safety. The systems may e.g. be categorized as providing longitudinal and lateral support or as systems monitoring the driver. Examples of longitudinal support systems are: *Intelligent Speed Adaptation (ISA)* (e.g. Brookhuis & de Ward, 1999; Regan et al., 2002; Várhelyi et al., 2004), *Adaptive cruise control (ACC)* (e.g. Hoedemaeker & Brookhuis, 1998), *Forward Collision Warning (FCW)* (e.g. Regan et al., 2002; and Adell et al., 2009), and *Automotive Collision Avoidance System (ACAS)* (e.g. Najm et al., 2006). Examples of lateral support systems: *Road-Departure Crash Warning System (RDCW)* (e.g. Wilson et al., 2007), *Lane Departure Warning (LDW)* (e.g. Regan, et al., 2002; Yu et al., 2008), *Lane Change Assistant (LCA)* (e.g. Rüder et al., 2002) and *Blind spot monitoring* (e.g. Ehlgen et al., 2008, Kuwana, & Itoh, 2008). *Fatigue Monitoring* (see e.g. Anund & Hjälmdahl, 2009; Rogado, et al., 2009) is an example of a system monitoring and warning the driver if his/her state of alertness is below a suitable level. A description of the systems and a more thorough categorisation of support systems can be found in van Driel (2007).

Knowledge of the safety effects of these systems is of great importance for decisions on their development and deployment. The safety evaluation of driver support systems is commonly classified into three areas: *System Safety*, *Human Machine Interaction* (HMI) and *Traffic Safety*. System safety covers safety issues concerning hardware and software design, particularly focusing on reliability, the tendency to malfunction or to go into a dangerous and/or unanticipated system mode. The HMI deals with interaction between the user and the system. Key issues are means of dialogue between the user and the systems, feedback to the user, design of buttons and controls, location in the car etc. Inappropriate design can lead to overload, underload or distraction of the driver. Traffic safety refers to the overall safety effect of system use and the outcomes of system safety and HMI. It also covers how a system may affect road user behaviour so as to alter the interaction between the driver, the vehicle, the road infrastructure and other road users. Evaluations of System Safety and HMI are wide areas and not part of this thesis. For an overview of these areas see e.g. ETSC (1999).

1.3 Evaluating traffic safety effects of driver support systems – a case of ISA

The traffic safety outcome of driver support systems may be estimated at three levels. The *maximum safety potential* states the highest safety benefit the system can provide, given the characteristics of the system. The *effects when in use* provide the safety effects when drivers use the system in their ordinary driving including interactions with other road users, behavioural changes, etc. The *true effects* provide the safety effects that actually reduce fatalities and trauma because they are the observable effects of the system when it is implemented. This is dependent on if (and how much) the drivers employ the system in reality.

1.3.1 The maximum traffic safety potential of driver support systems

The maximum traffic safety potential is the theoretical capacity of a system to improve traffic safety. It is an estimate of the number of accidents, injuries and fatalities that the functionality of the system may prevent or mitigate. The functionality of the system provides information about the positive behavioural change that may be expected. Knowledge about the connection between this behaviour and the accident risk provides the basis for estimating the safety effect. These estimates assume that the drivers use the system as intended by the designers, and any other behavioural change the usage might lead to is disregarded.

The maximum traffic safety potential of ISA

The principle behind the Intelligent Speed Adaptation (ISA) system is to support the driver not to exceed the legal speed limits. The system monitors the current speed limit (through e.g. GPS and digital maps containing information about speed limits) and informs/advises the driver not to exceed it or automatically limits the speed of the vehicle to the speed limit. In addition to this functionality, some versions of the system integrate further speed restrictions in critical situations (e.g. sharp curves, slippery road or poor visibility).

In theory, the maximum safety potential of this system is achieved if it prevents all speeding (and in some systems further limits the speed in critical situations). This implies, firstly, that the system is impossible to override or that drivers always choose to follow its recommendations, and, secondly, that all vehicles are equipped with the system and it is always active. Knowledge about the speeding behaviour and the relationship between speed and accidents contributes to ascertaining the maximum safety potential of ISA.

Studies calculating the maximum safety potential of ISA have estimated a reduction of injury accidents (including fatalities) by between 20 and 70 %

depending on type of ISA, country and type of road (see e.g. Várhelyi, 2002; Carsten & Tate, 2005; Carsten et al., 2006).

1.3.2 The traffic safety effects of driver support systems in use

A more realistic estimate of the traffic safety effects requires evaluation of the effects of the system while it is in use. When calculating the maximum safety potential, the functionality, as described by the designers/engineers, provides the basis for the evaluation. At this level, the actual behaviour of drivers constitutes the basis for providing an estimate of the traffic safety effects of using the system. How the system is used by drivers may be quite different from how it was intended to be used. Hence, actual use may also provide a number of unexpected and sometimes unwanted behavioural changes, which may be due to many different things, e.g., the driver's understanding of what the system does, and is capable of doing, or perception of how the system best fulfils his/her needs and requirements. Moreover, this can be influenced by external factors like penetration rate, coexistence with other systems, familiarity with the route, etc.

A number of guidelines, manuals and recommendations are available for the evaluation of the traffic safety effects when the system is in use, e. g. the ADVISORS framework (Parkes et al., 2001), the VIKING Guidelines (Kulmala et al., 2002), the RESPONSE 3 Code of Practice (Schwarz et al., 2006), the TEMPO handbook (Tarry et al., 2007) and the FESTA handbook (FESTA, 2008).

Investigation of the traffic safety effects of a system in use could either be carried out in real life (field trials) or in a driving simulator. Both settings have pros and cons. The imaginary world of the driving simulator offers the possibility of repeating the same situation, and flexibility when composing the test route and traffic environment. It also makes it possible to study critical safety situations, which would be too dangerous to study in real life. Still, the driving simulator does not offer the complexity of the real driving environment and cannot provide real interactions with other road users like the real world can do. The real life trials provide a very realistic quasi experimental setting that limits the validation problems.

When studying these traffic safety effects, it is important to include both driver behaviour and state. Driver behaviour should be investigated in terms of desired/expected behaviour and (unexpected/unwanted) behavioural adaptations. Which indicators to use are influenced by the hypothesised effects and the experimental layout, but some important variables regarding traffic safety are speed, headway, law abidance and interaction with other road users. Driver state

might be described by permanent and temporary factors. Permanent factors are those that stay (relatively) constant in the short term e.g. age, gender and mileage. Temporary factors such as workload, distraction, and the driver's emotional state vary in a shorter time span. Emotional responses like anger and irritation while driving may interfere with attention, perception, information processing and motoric reactions and make the driver more disposed to aggressive behaviour (for a review see Ulleberg, 2004). Further, it is important to consider the layout of the trial especially regarding selection of participants, choice of test area/route, experimental design, duration of the trial and instructions/information given to the participants.

The traffic safety effects of ISA when in use

ISA systems have been tested in various field and simulator tests mostly across Europe and Australia. These trials have found that the systems reduced mean speeds and speed variance (see e.g. *paper III,* Brookhuis & de Waard, 1997; Carsten & Fowkes, 2000; Lahrmann et al., 2001; Hjälmdahl, et al., 2002; Regan et al., 2004; Várhelyi et al., 2004; Regan et al., 2005). In addition, improved behaviour towards other road users and slightly larger headways have been found, but also some negative behavioural modifications such as forgetting to adjust the speed to the actual speed limit when not supported by the system (Hjälmdahl & Várhelyi, 2004).

Armed with knowledge of driver behaviour and driver state, one may make an estimate of the traffic safety effects when the system is in use. However, to be able to do so it is also necessary to examine the relationship between driver behaviour /driver state and traffic safety, but knowledge of this relationship is in many cases insufficient. Since the most examined relationship is the one between speed and accident risk/severity (see e.g. Finch et al., 1994; Elvik & Vaa, 2004; Nilsson, 2004), most numeric estimates are based on speed changes. Nevertheless, other driver behaviour or information about driver state should not be disregarded. Based on the reduction in mean speeds, the ISA system is estimated to reduce injury accidents by between 8 % and 25 % and fatal accidents by between 10 % and 32 %, under the assumption that all cars are equipped with an AAP (Active Accelerator Pedal) and that the system is permanently active (see e.g. Hjälmdahl et al., 2002). Regarding the driver state, several studies have shown small increases in workload and deterioration in the drivers' emotional response, especially for drivers who were sceptical about the system before the trial started or for drivers who experienced system malfunction, see e.g. *paper I, paper II and paper III.* The reduction in speed level and speed variance, the tendency of increased headway and improved behaviour towards other road users speak for improved traffic safety. On the other hand, forgetting to adjust the speed when the system is off,

increased workload and deterioration in emotional state may have negative effects on traffic safety.

In addition to the estimate of the traffic safety effects summarized above, it is important to address the long-term effects of using driver support systems. Most evaluations of systems are done over a short time period, not allowing the drivers to really use the system as they would if the system was permanently installed in their own cars. It has been shown that the duration the system is used has a significant impact on its effects, where e.g. the speed reduction decreases over time (Hjälmdahl, 2004) and the emotional state deteriorates further (*paper I*). This indicates a danger of overestimating the traffic safety effects when systems are only evaluated after short-term usage.

1.3.3 The true traffic safety effects of driver support systems

To estimate the true safety effects when a system is implemented, the effects when the system is in use have to be complemented with an estimate of how much it is actually going to be used. Only when the system is employed can it reduce fatalities and trauma. Hence, acceptance of it is vital. As e.g. Najm et al. (2006) states: "driver acceptance is the precondition that will permit new automotive technologies to achieve their forecasted benefit levels".

Acceptance is individual and based on what is known, understood and believed by the driver. It is the driver's personal attitudes, expectations, experiences and subjective evaluation that form the acceptance (or lack thereof) (Schade & Baum, 2007). Driver opinions about and experiences with a certain system are often collected and presented as information on acceptance. Although this information is interesting, it is not the same as acceptance of the system. The link between driver experiences and acceptance is missing, which hinders the evaluation of acceptance and how it is affected by the drivers' expectations and experiences. This in turn influences the extent of usage and consequently the true effects.

True traffic safety effects of ISA

The true traffic safety effects of ISA are unfortunately not possible to ascertain, since the actual use of the system cannot be estimated. If more was known about the acceptance of ISA, it would be easier to estimate the extent of usage and thereby also the true effects. This knowledge gap leads us to examine the concept of acceptance and in what way experiences influence drivers' acceptance.

1.4 Research objectives

The original objective of this research was to investigate driver experiences and acceptance of a driver support system, namely Intelligent Speed Adaptation (ISA). As the work progressed it became clear that what was meant by 'acceptance' was not clear, making it impossible to achieve the original objective. The extended objective of the research is hence to investigate driver experiences of ISA and to examine the concept of acceptance of driver support systems and how drivers' experiences influence their acceptance.

1.5 The scope of the thesis

The scope of this thesis is to investigate drivers' experiences of the driver support system ISA, the concept of acceptance in the context of driver support systems and how driver experiences influence acceptance. The thesis consists of four papers and an introductory/summarizing section. *Papers I, II* and *III* examine driver experiences. *Papers II* and *III* identify problems with present-day research regarding driver acceptance. *Paper IV* considers the concept of acceptance of driver support systems and a pilot test of an acceptance model. For a schematic diagram of the scope of the thesis see Figure 1.

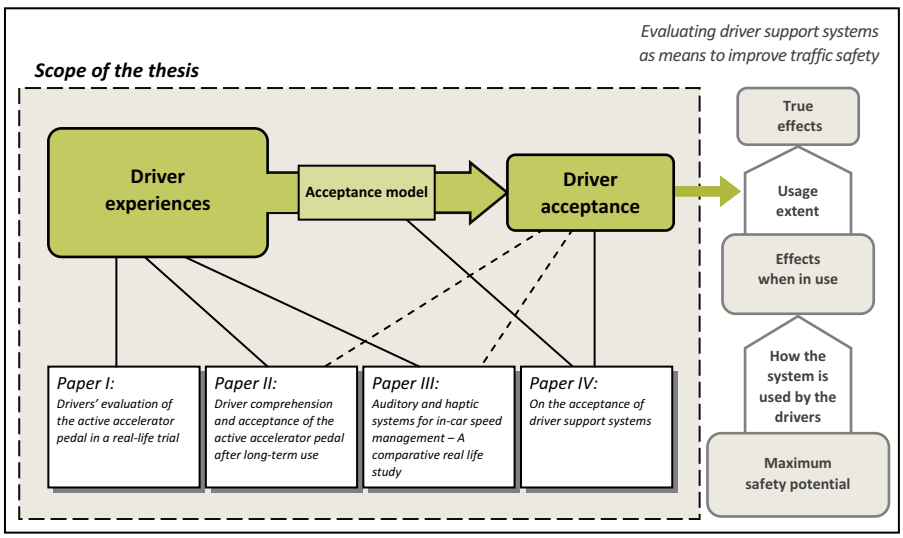

Figure 1: The scope of the thesis.

The introductory/summarizing section consists of 5 chapters:

- This chapter, *chapter 1*, provides the background and objectives of the thesis.

- *Chapter 2* focuses on drivers' experiences with ISA (Intelligent Speed Adaptation). The ISA-systems AAP (Active Accelerator Pedal) and BEEP (an ISA system, mainly providing auditory feedback) are described, as are the two field trials used to study drivers' experiences of ISA-systems. The effects on driver behaviour, found in the two trials, are briefly described and a more extensive summary of drivers' experiences with the systems is provided. The chapter ends with a discussion on the implications of the findings.

- *Chapter 3 contains* various definitions of acceptance. Considerations when defining and working on acceptance are discussed and a new definition is proposed. The chapter also describes the various ways of assessing acceptance and how these relate to the definitions. It ends with a discussion on the limitations of the methods used today.

- C*hapter 4* provides an overview of prevalent frameworks and models for understanding what affects acceptance. It also presents the results of a first pilot test to explore the possibilities of using the Unified Theory of Acceptance and Use of Technology for studying acceptance of driver support systems.

- *Chapter 5* discusses the implications and conclusions of the thesis and proposes ideas for further research.

2 Driver experiences of ISA

"The only source of knowledge is experience."

Albert Einstein

The driver's individual decision on the use of a certain driver support system is based on his/her knowledge, understanding and beliefs regarding issues related to the system. One very influential source for this is the drivers' own experiences with it, which might be different from the effects of the system measured by external observers.

2.1 ISA systems

Intelligent Speed Adaptation (ISA) is the generic name for a driver support system that "knows" the actual speed limit and uses that information to inform/support/limit the driver to comply with it. There are several ways to categorise these systems. One dimension used is how intervening the systems are: An *Informative* system displays the speed limit to the driver; an *Intervening* system reminds the driver when the speed limit is exceeded. A *Limiting* system limits vehicle speed to the speed limit.

Another dimension relates to the characteristics of the speed recommended by the system. A *Fixed* system uses the posted speed limits; a *Variable* system additionally lowers the recommended speed due to prevailing conditions e.g. road characteristics like sharp curves, zebra crossings. A *Dynamic* system also lowers the recommended speed due to dynamically changing conditions e.g. fog, slippery road surface, accident ahead.

A third dimension for differentiating ISA systems is how *voluntary* the use of the system is. The level of voluntariness can either refer to whether the driver can turn on and off the ISA system that is installed in his/her car, or to whether it is voluntary or *mandatory* to have the system installed in one's car.

There are many different types of ISA systems, using different means to interact with the driver. In different trials, information has e.g. been given to the driver through a speed limit sign below the speedometer, text messages displayed on the simulator screen, a colour coded display together with auditory messages, flashing red light together with beep-sound, flashing red LED display together with a spoken message, haptic throttle (counter pressure in the accelerator pedal), 'dead throttle' (pressing down the accelerator pedal when the speed limit is reached will have no effect, and no feedback in the accelerator pedal is given) and seatbelt vibrations, see e.g. *papers I, II and III*, Saad and Malaterre (1982), Nilsson and

Berlin (1992), Almquist and Nygård (1997), Brookhuis and de Waard (1997), Brookhuis and de Waard (1999), Carsten and Fowkes (2000), Lahrman et al. (2001), Varhelyi and Mäkinen (2001) and Adell et al. (2009).

Two different systems were used in the trials reported in this thesis; the active accelerator pedal (AAP) and the BEEP system. Both can be classified as fixed, intervening systems. Within the test area the use of the system was mandatory; the system could not be switched off. Outside the test area the use of the system was voluntary.

2.1.1 The Active Accelerator Pedal system

The Active Accelerator Pedal (AAP) system used in the trials gave the driver continuous visual information about the prevailing speed limit and haptic support/feedback when the current speed limit was exceeded. The visual information consisted of a dashboard-mounted display, see Figure 2. The haptic feedback consisted of an Active Accelerator Pedal (AAP) exerting a counterforce in the throttle at speeds over the current speed limit. The throttle had to be pressed approximately three to five times harder than normal in order to override the counterforce. The actual speed limit was provided by an onboard digital map combined with GPS.

Figure 2: The display showing the current speed limit. (Published with the kind permission of SG Utveckling)

2.1.2 The BEEP system

The BEEP system used in the trial gave the driver continuous visual information about the prevailing speed limit, and auditory and visual warnings when the speed limit was exceeded. The visual information was identical to the information given by the AAP system, see Figure 2. When the speed limit was exceeded, a small red light flashing on the display and a beep sound warned the driver. The sound was a 3500 Hz tone with duration of 0.1 seconds. It was repeated as long as the speed

was higher than the speed limit and the frequency of the repetitions increased the more the speed limit was exceeded. The longest time interval between the beeps was 1.5 seconds at the lowest speeding, and when the speed limit was exceeded by 20 km/h or more the beep turned into a continuous tone. The loudness level was 75 dBA when intermittent and 78 dBA when continuous.

2.2 Two field-trials with ISA

Two different field trials with ISA are employed in this thesis to study the drivers' experiences of ISA-systems, namely a large-scale, long-term field trial with AAP and a comparative field study on AAP and BEEP. First, short descriptions of the two trials are given below, followed by a discussion of the effects on driver behaviour found in those two trials. Thereafter the drivers' experiences are presented in terms of experienced effects, workload, emotional state and acceptance-related issues, followed by findings regarding effects of duration of use, driver characteristics, region, type of ISA and experiences of a malfunctioning system. Finally, the chapter ends with a discussion of the implications from the findings.

2.2.1 Large-scale field trial with AAP

A long-term field trial with the Active Accelerator Pedal system (AAP) was carried out between 2000 and 2001 in Lund, Sweden, as part of a national large-scale ISA trial. The system was installed in 281 passenger cars (247 owned by private drivers and 34 owned by companies) and the owners continued to use their cars with the system running for between 6 and 12 months. The system was activated automatically when the vehicle was within the city of Lund (the test area) and could not be turned off. The evaluation was designed as a short/long-term usage within-subjects study, using *gender*, *age*, *initial attitude* towards the system, and *driver type* (private or company car driver) as between-subject factors. Driver experiences were elicited by questionnaires after one month of use (short-term use) and at the end of the trial (long-term use). The short-term response rate was 86%, the long-term 82%, and 80% of the drivers answered both questionnaires. For further information about the trial and the analysis of the data see *papers I and II.*

Two thirds of the drivers reported some level of malfunctioning of the system. These issues were mainly related to technological problems with the ISA system or the interaction between the system and the car. Problems experienced by the drivers were e.g. delayed throttle response and continuous counter pressure in the throttle. Errors in the digital map providing the speed limits or difficulty with the navigation unit also caused some problems with the functionality. In the group of drivers reporting malfunctioning, there was an overrepresentation of company car

drivers (32 of the 34 were company car drivers). No differences in gender (χ^2, *p=0.29)*, age (χ^2, *p=0.47)* or initial attitude (χ^2, *p=0.99)* could be found among test drivers with malfunctioning systems compared to drivers not reporting problems.

2.2.2 Comparative study on AAP and BEEP

The comparative field trials with the AAP and the BEEP systems were carried out in Hungary and Spain in 2003 and 2004. The systems were installed in the participants' private cars and each system was used in their regular driving for one month. All 39 participants (20 Hungarian +19 Spaniards) tested both systems; half of the drivers used the AAP first followed by the BEEP and the other half vice versa. The systems were activated automatically when the vehicle was within the test areas (the cities of Debrecen and Mataró) and could not be turned off. The evaluation was designed as a before/during/after study using *system* as a within-subject factor, and *country* as a between-subject factor. Data on the use of each system was collected during (logged data) and after (questionnaire) one month of usage. All the drivers answered all the questionnaires with the exception of one Hungarian driver who did not answer the last questionnaire. For further information about the trial and the analysis of the data see *paper III.*

The systems were based on an improved version of the AAP-system used in the large-scale field trial held in Lund, Sweden, between 2000 and 2001. Nevertheless, there were still some technological problems during the trial, mainly regarding the accuracy of the map and the fact that the system was also active outside the test area. In total, 12 (of the 38 drivers answering the question) drivers reported problems with the AAP and 11 with the BEEP system.

2.3 Effects on driver behaviour

The effects on driver behaviour when using the AAP in the large-scale field trial were reported by Hjälmdahl et al. (2002), Hjälmdahl and Várhelyi (2004) and Várhelyi et al. (2004). The results showed that the test drivers drove at lower and more even speeds when they used the AAP. Compliance with the speed limits improved. There were no significant changes in time consumption, but the results indicate a decrease rather than an increase. The average amount of CO and NO_x-emissions per car decreased. The results provided no evidence of compensatory behaviour, either at intersections (approach speeds and turning speeds) or outside the test area (speed level). Further, there were no signs of spill-over effects in the form of lower speeds outside the test area. However, there were some tendencies of negative behavioural effects where drivers forgot to adapt their speed to the speed limits or to the prevailing conditions when they were not supported by the system.

The effects on driver behaviour when using the AAP and the BEEP systems in the comparative study carried out in Hungary and Spain were reported in *paper III*. The results are very much in line with the findings of the large-scale field trial in Lund, Sweden. Both the AAP and the BEEP system decreased the mean speed as well as the 85 percentile speed. The largest effects of both ISA systems were found at the highest speeds. The speed variance decreased on all the analysed road types, except on motorways with a 120 km/h speed limit in Spain. The AAP had larger speed reducing effects than the BEEP on roads with speed limits of 50 and 80 km/h. The results on 50 km/h streets showed that the effects of both systems were larger in Spain than in Hungary. After the systems were removed from the vehicles, the speed levels increased, in both countries, to almost that of the before situation.

2.4 Driver experiences

The results below give a general picture of the drivers' experiences of the system studied. The results from *papers I and II* showed that technological problems influenced the drivers' experiences. To illustrate driver experiences of the system, separated from technological problems, the results in cases where the drivers reported malfunctioning system are duly analysed and reported separately below. More detailed results of the trials are given in *papers I, II and III.*

2.4.1 Experienced effects

The largest experienced effect when driving with the ISA systems was a considerable reduction in the risk of being fined for speeding in all three countries. The drivers also experienced a considerable reduction in speed within the test area. According to the test drivers, the use of the AAP also made it easier to comply with the speed limits (*paper I*) and they expected the speeds to decrease if all cars were equipped with the system (*paper III*). The drivers also felt a slight increase in their own safety and an increase in travel time when driving with the ISA systems.

2.4.2 Workload

There were some differences in the reported workload in the three countries. The subjective workload was assessed by six factors according to NASA-TLX (Byers et al., 1989). In Sweden, one workload factor, namely time pressure, showed an increase in workload, and two workload factors, i.e., performance and the need to accelerate and brake (long-term experiences), showed a decrease. The results from Spain showed no indications of increased workload when driving with either of the two ISA systems, whereas the Hungarian drivers noted an increased workload

in four of the six factors, namely physical demand, time pressure, effort and performance.

2.4.3 Emotional state

The Swedish drivers noted a reduction in driving enjoyment and an increase in the feeling of obstructing the traffic. The Hungarian and Spanish drivers reported increased irritation, increased feeling of obstructing the traffic and increased feeling of being controlled as well as a tendency of reduced enjoyment when driving with the AAP.

2.4.4 Acceptance-related findings

The results below cover some of the indicators of driver acceptance used today.

The concept of the ISA was rated positively by a majority of the Swedish, Hungarian and Spanish drivers on a five-grade scale from "very bad" to "very good".

The system was considered to be useful, while it was considered neutral on the satisfaction scale (van der Laan et al. 1997). In Sweden (where a somewhat modified version was used based on a previous translation of the items into Swedish), the system was considered 'good', 'important', 'effective', 'clear' and 'informing' rather than their opposites, which is an indication of relatively high usefulness. Further, the system was reported to be slightly 'pleasant' and 'ugly' and neither 'irritating' nor 'soothing' and neither 'uncomfortable' nor 'comfortable' which indicated neither positive nor negative satisfaction. In Hungary and Spain both systems were considered 'good', 'effective', 'useful', 'assisting' and 'raising alertness' as well as neither 'unpleasant' nor 'pleasant' and neither 'undesirable' nor 'desirable'. The BEEP system was considered to be 'annoying' and 'irritating' while the AAP was not.

The Swedish drivers generally state that they 'never' or 'seldom' overrode the system. Whether this should be interpreted as an indication of acceptance or not depends, like all other measurements, on the definition of acceptance as well as on whether the possibility of overriding the system is seen as utilizing a functionality of the system or as turning off the system.

After the trials were finished, about 28 % of the Swedish drivers wanted to keep the system in their car. In Hungary and Spain about 50 % wanted to keep the AAP while about 65 % wanted to keep the BEEP system.

2.4.5 Effects of duration of use on driver experiences of AAP

Data from two time periods were considered in the Swedish trial, short-term (after one month of usage) and long-term (after an additional 5 to 11 months of usage). When comparing these periods, differences were found in the drivers' assessment of speed, their performance, driving enjoyment, stress and awareness of speed limits outside the test area.

The experienced speed change differed in magnitude between the two measurement periods. In the short-term, the drivers reported changes of the same magnitude regardless of speed limits, as opposed to larger reductions in streets with lower speed limits in the long term. The driving performance was rated higher in the long-term compared to the short-term, whereas the driving enjoyment decreased further and the stress increased. The awareness of speed limits outside the test area decreased over time.

2.4.6 Effects of driver characteristics on their experiences of AAP

The large-scale field trial with AAP in Lund, Sweden, where 281 drivers participated, made it possible to study the experiences of different driver groups. The drivers were categorised according to their age, gender, initial attitude towards the system and whether they used the system in their private car or in a company car.

Main effects were found for initial attitude, age, gender and driver type. Most of the effects were found for initial attitude which mainly influenced workload, emotional state and usage. Overall, the initially negative drivers distinguished themselves from the initially positive drivers in that they experienced more difficulty with the system. Four of the six workload factors were negatively affected (attention, time pressure, effort and frustration), as were two of the four factors for emotional state (stress and driving enjoyment). The initially negative drivers also found the system less attractive and pleasant and stated that they overrode the system more frequently than the positive drivers did.

Effects of age were found for usefulness/satisfaction, willingness to keep the system after the trial ended, workload and usage, indicating that younger drivers found the usefulness of and satisfaction with the system to be worse compared to older drivers, and were willing to keep the system after the trial ended to a lower extent compared to middle-aged drivers. Older drivers rated their driving performance with the system more highly and reported lower frustration than the younger drivers did. Further, main effects of age groups were found in the usage of the system, which indicated that the older drivers perceived the counter force as more of a command to lower their speed than as a support to keep the speed limit.

Younger drivers stated that they overrode the system more frequently compared to older drivers. No systematic correlations of driver experiences due to gender or driver type were found.

The interaction effects indicated that women were more influenced by their initial attitude and their driver type (private/company car) compared to men. Similarly, company car drivers and older drivers were more influenced by their initial attitude than private car drivers and younger drivers, respectively.

Interaction effects with time were mainly found between *time and driver type* and *time and attitude*. Generally, the effects showed larger changes over time for company car drivers and for the initially negative drivers. Interaction effects were mainly found on experienced speed changes and emotional state.

2.4.7 Differences in experiences of Swedish, Hungarian and Spanish drivers

Most of the short-term results from Sweden concur with the results of AAP use in Hungary and Spain, see Table 1. The differences among the countries are to be found in the workload assessment, the effect on driving enjoyment and the willingness to keep the system after the trials ended. The Hungarian drivers stated that the workload increased, whereas no change was found in Spain, while the Swedish drivers reported both an increase and a decrease in various workload factors. The decrease in driving enjoyment communicated by the drivers in Sweden was not confirmed by the drivers in Hungary and Spain, although some indications in that direction were found, especially in Hungary. The difference in willingness to keep the system after the trial ended between Swedish drivers on the one hand and Hungarian and Spanish drivers on the other, was most likely due to the relatively larger number of system failures in the Swedish trial.

Table 1: Comparison of results of experienced effects of AAP after one month's use in three different "regional typical" countries in Europe

	Hungary	Spain	Sweden
Experienced effects			
Safety	Moderate increase	Small increase	Small increase
Speed change	Moderate decrease	Small to significant decrease (varying with speed limit)	Moderate decrease
Getting fined for speeding	Moderate decrease	Significant decrease	Significant decrease
Travel time	Moderate increase	Moderate increase	Moderate increase
Fuel consumption	No change	No change	No change
Workload			
Workload	Moderate increase	No change	No overall change
Emotional state			
Irritation	Small increase	Small increase	Small increase (only those with mal-functioning system)
Stress	No change	No change	No change
Driving enjoyment	No change	No change	Small decrease
Acceptance-related issues			
The concept of AAP	17 of 19 drivers positive (89 %)	16 of 18 drivers positive (89 %)	126 of 160 drivers positive (79 %)
System features	Usefulness: moderate positive Satisfactory: neutral	Usefulness: moderate positive Satisfactory: neutral	Usefulness: moderate positive Satisfactory: neutral
Keeping the system	10 of 20 drivers positive (50 %)	9 of 17 drivers positive (53 %)	44 of 155 drivers positive (28%)

2.4.8 Differences in experiences of using AAP and BEEP

Comparing the Hungarian and Spanish drivers' experiences when using the AAP versus the BEEP system, workload factors, aspects of the emotional state and system features stand out. According to the drivers, the AAP increased the 'physical demand' and the 'effort' of driving. The BEEP increased the 'mental demand' according to the Spanish drivers. When using the AAP, there were some indications of reduced 'driving enjoyment'. The BEEP system was considered to be more 'annoying' and 'irritating' and 'raising alertness' compared to the AAP. Nevertheless, the drivers were more positive to having the BEEP system in their cars compared to having the AAP. When choosing between the systems, more drivers preferred the BEEP system compared to the AAP.

2.4.9 Effects on driver experiences of malfunctioning system

Technological problems caused two thirds of the Swedish test drivers to report a malfunctioning system. These drivers' experiences were similar to those of the initially negative drivers (no difference in initial attitude could be found among the drivers reporting technological problems). They reported higher workload (effort and frustration) as well as deterioration in their emotional state (irritation and stress) and higher override rate compared to drivers who did not report technological problems. However, they also noted smaller effects of the system, such as a smaller reduction in the risk of being fined for speeding and smaller speed reductions.

The interaction effects indicated that women were more influenced by system failure compared to men. No interaction effects with time were found, i.e., time did not influence the experiences with malfunctioning systems.

2.5 Implications of the findings of the field trials

The studies in *papers I, II and III* show that the drivers found the system to be effective in decreasing their speed and believed that their risk of being fined for speeding decreased significantly. The emotional state deteriorated somewhat and the subjective workload was also affected for some of the drivers. The drivers found the concept of the system good and rated the usefulness of the system moderately high. However, satisfaction with the system and the willingness to keep the system were lower.

Generally, the results suggest that the most typically sceptical driver was a young, male, company car driver with an initially negative attitude to the system. The most enthusiastic driver was an older, female, private driver with an initially positive attitude.

The results also showed that the experienced effects (speed, travel time, risk of being fined for speeding etc.) were relatively uncorrelated with any of the driver variables, namely initial attitude, age, gender and driver type. The drivers' initial attitude correlated with their emotional experiences, their assessment of the system features and their override rate. The age correlated with the drivers' assessment of the system's features and usage of the system (including override rate) as well as the willingness to keep it. No systematic correlations due to gender or driver type were found.

The results from *paper I* as well as results regarding observed speed behaviour (Várhelyi et al., 2004) point to the fact that adaptation to the system was still

ongoing after one month of use. It takes more than one month of driving to get used to and incorporate a new driver support system in the driving task. The reduction in driving enjoyment and increase in stress suggest that negative emotional experiences may increase rather than decrease over time. The reduced awareness of speed limits outside the test area points to an increased delegation of responsibility over time. These time effects have to be acknowledged when evaluating driver support systems.

In a real life trial, there are always external variables included in the drivers' evaluation of the system, apart from the system itself. In the case of ISA, the functionality of the system is based on speed limits determined by the road authority. The correspondence between the speed limits and the driver's opinion about an appropriate speed will, for example, have an impact on how the system is experienced by the drivers. In that sense, it is not only the system itself that is evaluated by the drivers, but the "package" of using the system in real life. Depending on the "settings" in real life, the experiences of using it may vary. It is often difficult to separate the system effects from other external effects.

The similar results from the trials in the different regions in Europe indicate, however, that the different "settings" within Europe have no major influence on the experiences of using the systems; hence the findings might be generalized from one European country to another. The results, presented in *paper III,* show that many overall trends are the same in Hungary, Spain and Sweden although the exact magnitudes cannot be compared. However, the results also show that the subjective workload should not be generalized.

Comparing the AAP and the BEEP systems in Hungary and Spain, the drivers generally preferred the BEEP system to the AAP, Despite assessing the BEEP system as being more 'irritating' and 'annoying' compared to the AAP. However, there were indications of higher subjective workload when using the AAP.

Technological problems are difficult to avoid in field trials with newly developed driver support systems. These are likely to occur especially when prototypes are used. The ambition would of course be to avoid any technological problems by having a perfect system. Unfortunately, this is not achievable even in the best of worlds and in the real world one has to settle for "good enough". In the large-scale field trial in Lund, carried out between 2000 and 2001, there were significant technological problems. It is sometimes hard to know the extent of technological problems in advance and one may of course question whether the system used in that trial was "good enough". In an attempt to separate the effects of the technological problems, the results concerning drivers who had malfunctioning systems have been shown separately. This may also be debated, since more

sceptical drivers may be more prone to report technological problems. However, there was no statistically significant correlation between the initial attitude of the driver and whether the driver reported problems. The technological problems had an impact on the drivers' experiences with the system. In fact those with technological problems were the most negative driver group, also reporting less positive effects of the system (smaller decrease in the risk of being fined for speeding). This illustrates how fundamental the reliability of the system is to the drivers. The lack of interaction effects between time and malfunctioning systems suggests that technological problems influence the driver quite early in the adaptation process. These effects are also unlikely to change over time.

Attempts to assess the acceptance of the systems are made *in Papers II and III*. The drivers' opinion about the concept of ISA, their assessment of the usefulness of and satisfaction with the system as well as their willingness to have/keep and pay for the system are used as indicators of acceptance. The findings in *paper II* show that the concept of the AAP was rated positively by almost 80 % of the Swedish drivers while barely 30 % of these drivers were willing to keep the system. If these two measurements had been used in two different set-ups (different systems, driver groups, experimental settings etc), two different conclusions on the level of acceptance would have been made, going in two opposing directions.

A similar problem was found in the study reported in *paper III,* where more drivers wanted to keep the BEEP system than the AAP even though the BEEP system was perceived as more 'irritating' and 'annoying', both of which are satisfaction items on the usefulness/satisfaction acceptance scale (van der Laan et al., 1997).

The results reported in *papers II* and *III* do not give a clear picture of the acceptance of the systems. Instead, they highlight the problematic situation in which today's acceptance research on driver support systems finds itself. The weak common ground in terms of the definition of acceptance has produced numerous different measurements, generating problems when e.g. interpreting and comparing results from different studies regarding acceptance of driver support systems.

3 What is acceptance?

"The contrast between the drivers' response to the concept of the AAP and the willingness to keep the system puts a clear focus on the importance of defining acceptance and developing a tool to ensure reliable assessment of acceptance and make inter-study comparisons possible."

Paper II

Despite the recognized importance of acceptance, the understanding of acceptance of driver support systems is often taken for granted. While many studies claim to have measured acceptance, few have defined what it is. As Regan et al. (2002) put it: "While everyone seems to know what acceptability is, and all agree that acceptability is important, there is no consistency across studies as to what 'acceptability' is and how to measure it". Although there is no common definition of acceptance, some definitions of acceptance as well as descriptions of different types of acceptances can be found in the literature.

3.1 Present definitions of driver acceptance

3.1.1 Five different ways of defining acceptance

As the analysis of the literature review presented in *paper IV* shows, the acceptance definitions identified in the literature can be classified into five categories. The first category uses the word "accept" to define acceptance. The second category is concerned with the needs and requirements of users (and other stakeholders). This may be interpreted as the usefulness of the system. The third category of definition sees acceptance as the sum of all attitudes, implying that other, for example, more emotionally formed attitudes are added to the more "rational" evaluation of the usefulness of the system (as in category 2). The fourth category focuses on the will to use the system. This definition of acceptance aims for a behavioural change and may be seen as being based on the earlier categories, in that the will to use a system is based on drivers' assessment of the usefulness of the system (as in category 2) as well as all other attitudes to the system and its effects (as in category 3). This fourth category stresses the will to act as a consequence. The fifth category of acceptance emphasizes the actual use of the system, which presumably is influenced by the will to use it (as in category 4).

Viewing the categories like this, they may to some extent be seen as a progression from assessing the usefulness of a system towards the actual use of that system, the later categories including the earlier ones, see Figure 3. This progression perspective, however, cannot include category 1, which uses the word "accept" to define acceptance, but does not provide any information about what is implied by acceptance or accept.

Definition categories

1	2	3	4	5
Using the word "accept"	Satisfying needs and requirements	Sum of attitudes	Willingness to use	Actual use

Figure 3: The five categories of acceptance, based on definitions found in the literature review.

3.1.2 Different dimensions of acceptance

There are also different types of acceptances described in the literature. Authors have made distinctions between attitudinal and behavioural acceptance (Kollman, 2000; Franken, 2007), between social and practical acceptance (Nielsen, 1993) and between different levels of problem awareness of the individual (Katteler, 2005).

Attitudinal acceptance is, according to Franken (2007), based on emotion and experience and provides a basis for accepting a system. Behavioural acceptance is displayed in the form of observable behaviour. Comparing to the definition categories described above, attitudinal acceptance is comparable to 'sum of attitudes' (category 3) and behavioural acceptance to the 'actual use' (category 5). Similar to this, Kollmann (2000) describes acceptance as consisting of three levels: the general connection of inner assessment and expectation (the attitude level), the acquisition or purchase of the product (the action level) and its voluntary use with a frequency greater than that of other traffic participants (the utilization level).

Social acceptability is described by an example (Nielsen, 1993): "Consider a system to investigate whether people applying for unemployment benefits are currently gainfully employed and thus have submitted fraudulent applications. The system might do this by asking applicants a number of questions and searching their answers for inconsistencies or profiles that are often indicative of cheaters. Some people may consider such a fraud-preventing system highly socially desirable, but others may find it offensive to subject applicants to this kind of quizzing and socially undesirable to delay benefits for people fitting certain profiles." Comparably, a driver might find it socially unacceptable for a government to impose a driver support system on a user, even if it results in reduction in road trauma. Practical acceptability includes dimensions like cost, compatibility, reliability, usefulness, etc.

Katteler (2005) defines different types of acceptances depending on the subject's awareness of the problem the support system is aimed at tackling. The well-

founded, firm acceptance indicates, apart from a positive attitude towards the system, that the individual is aware of the problem the system is designed to tackle. The opportunistic acceptance indicates low problem awareness and is likely, according to Katteler (2005), to be less stable and more sensitive to changes.

There is also discussion about 'conditional' and 'contextual' acceptance in the literature. Conditional acceptance indicates that acceptance is dependent on certain preconditions (Saad & Dionisio, 2007), e.g. "I will use the system if I am free to turn it off when I want to" or "I will use the system if everybody else does". Similarly, contextual acceptance indicates that acceptance depends on the situational context (Saad, 2004), e.g. "I will use the system on roads with speed cameras" or "I won't use the system in rush hour".

Goldenbeld (2003) makes a distinction between acceptance and support, where acceptance is the willingness to be subjected to something (e.g. pay taxes) while support is the liking for doing so. Vlassenroot et al. (2006) further claims that (public) support is a precondition for acceptance since it "defines the degree of acceptance or intentions people have to adapt or not to adapt to the desired behaviour". The sum of the individuals' acceptance indicates whether there is public support, according to Vlassenroot and de Mol (2007). By the reasoning of Vlassenroot et al. (2006) the willingness to do something has to be preceded by a liking for doing it.

Some stress the importance of making a distinction between acceptability and acceptance. Schade and Schlag (2003) define acceptability as the "prospective judgement of measures to be introduced in the future". Acceptability is measured when the subject has no experiences of the system, and is therefore an attitude construct. Acceptance, on the other hand, consists of attitudes including behavioural reactions after the introduction of a measure. Pianelli et al. (2007) differentiate between two types of acceptability: priori and posteriori acceptability. Priori acceptability is acceptability without experience of the system while posteriori acceptability is the acceptability after having tried the system. The posteriori acceptability includes experiences of the system, but does not necessarily include behavioural reactions, making it different from the acceptance described by Schade and Schlag (2003).

The literature also contains some statements on the purpose of investigating acceptance. Najm et al. (2006) claim that "driver acceptance is the precondition that will permit new automotive technologies to achieve their forecasted benefit levels" and that there is a need to determine whether drivers will accept and use the new technologies as intended. Further, Najm et al. (2006) state that driver acceptance provides a means to estimate drivers' interest in purchasing and using

new technology. "Driver acceptance measurement also provides a means to estimate drivers' interest in purchasing and using new technologies as a basis for estimating the safety benefit associated with its use." (Najm et al., 2006). Van der Laan et al. (1997) also see acceptance as the link to usage, thereby materializing the potential safety effects, whereas van Driel (2007) sees acceptance as a predictor of the willingness to buy a system.

3.2 Proposal for a new definition of acceptance

Working on driver acceptance makes it essential to understand the importance of a driver-centred view, as it is the driver who makes the decision to use or not use a system. Since acceptance is individual, it can only be based on an individual's personal attitudes, expectations, experiences and subjective evaluation of the system and the effects of using it (Schade & Baum, 2007). The effects of the system (e.g. reduction in accident risk) can only influence acceptance if they are known, understood and believed in by the driver. A misunderstanding of the system will influence acceptance as much as a correct conception.

It is also important to remember that focus should not be on the innovation per se or on political/policy goals. It has been recognized that, to achieve the acceptance and use of new systems, personal importance to the users has to be valued more highly than degree of innovation (see e.g. Ausserer & Risser, 2005). However, policies and political goals are often confused with the driver's personal goals. Societal goals and individuals goals do not necessarily coincide. For example, the policy goal behind ISA could be to increase traffic safety or to increase speed limit compliance. These goals might not be relevant to some drivers e.g. due to their feeling that safety measures are redundant because of their own personal driving skills (Brookhuis & Brown, 1992), or that speeding is not seen as a "real crime" (Corbett, 2001). Nevertheless, they might find that the system helps them to avoid speeding tickets or that they have an interest in innovative systems.

The multidimensional definition of acceptance proposed by Katteler (2005) is interesting and offers new dimensions to the level of acceptance. Katteler has studied ISA and uses awareness of the speed problem as the "problem awareness" dimension. However, this might not be the "problem" for which drivers wish to use the system. Similar systems are marketed as a problem-solver for speeding tickets.

The same argument can be raised against the approach chosen by Vlassenroot et al. (2006). The authors examine 'public support' for ISA since it "defines the degree of acceptance or intentions people have to adapt or not to adapt to the desired behaviour". In this approach drivers have to agree that high speeds are a

problem and that ISA is a good way of reducing them to demonstrate public support (Vlassenroot et al., 2006). It is true that these drivers will most likely demonstrate a high acceptance of ISA, but it is also possible that drivers who do not show support for the system on these terms may accept the system. If this were not the case, it would also raise the question of what traffic safety benefits a system like ISA would have if only used by drivers who already agree that high speeds are a problem and that ISA is a good way of dealing with them, see e.g. Hjälmdahl (2004) and Jamson (2006).

The use of the system is vital in striving to improve traffic safety by deploying driver support systems. It is the use of the system that will materialise its potential and hopefully produce benefits for the driver and the society. Neither attitudinal acceptance (Franken, 2007) nor support (Goldenbeld, 2003) requires any impact on the actual use of a system. Hence, the main aim and focus should be on behavioural acceptance (Franken, 2007), the utilization level as described by Kollmann (2000) or the acceptance definition category 5 – actual use (described above in Chapter 3.1.1), which emphasizes the use of the system. From this perspective, the second and third categories of acceptance definitions (usefulness and all attitudes), attitudinal acceptance (Franken, 2007) and the attitude level described by Kollmann (2000) influence the will to use and the actual usage, but are not to be seen as acceptance.

Obviously, it is not possible to assess the use of systems that are in the design phase. It is desirable, though, to accurately predict user acceptance as early as possible in the design process to be able to evaluate different alternatives and identify obstacles to overcome. Further, also for systems that are available to drivers, the use of the system has to be seen as a part of a process including the will to use as a step towards usage.

The following definition of acceptance is proposed:

Acceptance is the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving.

This definition has the advantages of considering the intention to use (which can be used early in the development phase) and of emphasising the importance of manifesting the intention in actual behaviour. Further, it also stresses the importance of focusing on the individual who makes the decision to use or not use a system and his/her understanding of the system. This definition clearly states that the level of acceptance is not believed to be limited to acceptance/non acceptance (nominal scale), but to be of a more continuous nature.

By this definition it follows that the driver does not necessarily have to like to use the system to demonstrate acceptance. To show high acceptance it is enough that the driver decides to use the system, which, under the given circumstances, is seen as the best option. In this way, tolerating the use of the system can be seen as part of acceptance. For example: a driver who normally would not choose to use an ISA system decides to use the system due to the amount of his speeding fines, or a driver agrees to use the system since it is required by law. Of course, the degree of acceptance could also be zero when the driver does not use the system and has no intention to do so.

3.3 Assessing acceptance

Considering the different definitions of acceptance, it is hardly surprising that there are almost as many ways to measure acceptance as there are researchers trying to measure it. Besides, the definition and meaning of 'acceptance' are usually taken for granted in ITS research, and most researchers assess acceptance without defining it. Below is a summary of the different ways to assess acceptance found in the literature review in *paper IV*.

3.3.1 Different ways to assess acceptance

The numerous ways of assessing acceptance found in the literature review are summarized into 9 groups (with 22 subgroups). Most authors use more than one measurement to assess acceptance, either from the same or from different measurement groups. Usually, the measurements used in the various studies are based on questionnaires, but there are also measurements based on interviews, focus groups, logged data and physiological measures. There are also acceptance studies with results concerning acceptance, but without describing how the results are obtained. For more information about the subgroups and references see *paper IV*.

- Using the word "**accept/acceptable**"

  This seems to be a quite common way to assess acceptance. Usually measurements in this category use phrases like "would you accept…?" or "how acceptable is… ?". Another way of measuring acceptance included in this group is the assessment of the "willingness to accept" something.

- **Usefulness and satisfaction**

  The most used method is the usefulness/satisfaction scale developed by van der Laan et al. (1997). This is a standardised procedure to estimate the usefulness of and satisfaction with a system. The driver assesses the system in question by means of nine five-point rating-scale items (useful – useless,

pleasant – unpleasant, bad – good, nice – annoying, effective – superfluous, irritating – likeable, assisting – worthless, undesirable – desirable and raising alertness – sleep-inducing). These bipolar scales are then combined into one usefulness score and one satisfaction score for the system. This method has been used in *papers II* and *III*.

Many studies use a variety of **usefulness** measurements as measures of acceptance, e.g. whether the system facilitates the driving task, affects the driving performance of oneself and/or affects the driving performance of others. This group also includes opinions about the effectiveness of the system and information about what kind of instructions/corrections one wants to receive from the system.

Some studies also use other measurements to assess **satisfaction** as a measure of acceptance. Examples from this group are a general assessment of satisfaction with the system, opinions on whether having the system is an advantage or disadvantage, the attractiveness/unattractiveness of the system, whether the system is disturbing or annoying and whether it is supportive or constructive.

- **Willingness to** submit to something

Quite a few studies use the willingness to subject to something as a measure of acceptance, and investigate the willingness to pay, either by posing an open question or a closed one with different price intervals. Further, willingness to buy, accept, have, keep, use and install, as well as the wish to shut down the system are indicators assigned to this group. This type of measurement is used in *papers II* and *III* where the drivers are asked whether they want to have, keep and pay for the system.

- **Use**

One group of measurements, which focuses on the use of the system, includes measurements of voluntary use, frequency of use and the action of shutting down the system. This group is sometimes measured by observed behaviour.

In *paper I*, the drivers state how often they overrode the system. This may be seen as a (indirect) measure of use. However, if it is depends on whether one sees overriding the system as not using the system or as utilizing a certain feature of the system.

- **General assessments**

Many researchers also use a general assessment to measure acceptance. Examples in this group would be to judge the concept/idea of a system, assess the popularity of the system, whether the driver is in favour of the system and whether the user would recommend or appreciate it if loved ones used the system. This type of measurement is used in *papers II* and *III* where the drivers are asked to rate the concept of the system.

- **Importance** of the system

Some researchers assess the importance of the system as an indicator of acceptance, e.g. ranking the importance of the system compared to other systems/measurements or a judgement of its necessity. Whether the driver supports an implementation is also included in this group.

- **Reliability** of the system

A few studies measure drivers' level of trust in the system or the credibility of the system (unclear whether the authors refer to their own judgement of the system or to the drivers' opinion about the system).

- **HMI** assessments

Some studies use assessment of the HMI (Human-Machine-Interaction) as a measurement for acceptance e.g. about the timing of the information given to the drivers, if they were startled by the information, if they could identify the source of the alert and if they wanted to modify the intensity of the feedback.

- **Physiological reactions**

One study also uses physiological reactions interpreted as stress to measure acceptance. This is done by measuring the heart rate of the driver.

3.3.2 Acceptance measures in relation to the definitions of acceptance

Most of the measurements used can be related to the definition categories of acceptance based on findings in the literature, see above in chapter 3.1. In this respect, the assessment using the word "accept" clearly relates to the first definition category but does not provide any further information about the meaning of acceptance. The usefulness/satisfaction scale proposed by van der Laan et al. (1997) reflects the third category of definition – the sum of attitudes. The usefulness measurement may be associated with the second definition (needs and requirements), and is a subset of the third definition category, as is the satisfaction assessment. The willingness to subject to something partly reflects the fourth category of definition – the willingness to use. However, the willingness to pay,

buy, accept, have, keep and install are also used as assessments of acceptance within this group. The other measurements do not clearly belong to any of the definition types, but one can assume that "have", "keep" and "install" aim at estimating the willingness to use. Some measurements aim at assessing the use of the system, which is the fifth category. The general assessment, importance and reliability of the system do not clearly reflect any of the definitions. However, these measurements indicate, to some degree, the attitude towards the system (category 3) and the usefulness of the system (category 2). Opinions about HMI and physiological reactions of stress do not reflect any of the definition categories.

3.3.3 Limitations of current ways of measuring acceptance

How to measure acceptance in a valid way does depend on how acceptance is defined. It is not surprising therefore that the weak common ground regarding acceptance definition has resulted in a large number of different attempts to measure acceptance. The large differences in the measures used indicate quite a large discrepancy in the understanding of acceptance as well as in what are believed to be important and valid indicators of acceptance.

The many different ways of assessing acceptance may cause confusion and lead to incorrect conclusions or interpretations. Illustrations of problems with the current ways of measuring acceptance are found in *paper II* and *paper III*.

One interpretation of the different results is that the measurements used do not measure the same kind of acceptance. The concept of the system and the usefulness/satisfaction scale relate to definition category 3 (sum of all attitudes) while the willingness to keep relates to category 4 (willingness to use). However, even if more measurements assessing the same kind of acceptance were used, there would be no guarantee that the results would concur, since validations of the measurements used are virtually non-existent. Most researchers define acceptance implicitly by the measurements they use to assess it, making validation superfluous.

The present situation is troublesome. If acceptance has not been defined, then we cannot be sure that the tool we use to measure it will give valid results. Without knowing how acceptance is defined, it is impossible to understand how drivers' experiences influence it. The inconstancy of acceptance definitions (implicitly defined or not), and of measurements and thereby the diversity of results, even though collected in the same experiment, present a breeding ground for misinterpretations and misuse of the results. What is more, it makes comparisons between systems and settings almost impossible.

4 Acceptance Models

"Researchers are confronted with a choice among a multitude of models and find that they must "pick and choose" constructs across the models, or choose a "favoured model" and largely ignore the contributions from alternative models. Thus, there is a need for a review and synthesis in order to progress toward a unified view of user acceptance."

Venkatesh et al. (2003)

A definition of acceptance has now been proposed. However, for an understanding of how acceptance is formed and what factors influence it, a model is a useful tool.

An important component in this definition of acceptance is behaviour (use). The most frequently used model to explain behaviour in the area of traffic safety is the Theory of Planned Behaviour (Ajzen, 1991). According to this theory, behaviour is determined by people's attitude towards the behaviour, their subjective norm and their perceived behavioural control via their intention to perform the behaviour. In the context of driver support systems, the Theory of Planned Behaviour has been used to study e.g. violations of speed limits (Wallén Warner & Åberg, 2006 and Wallén Warner & Åberg, 2008), but the model has not been used to study the use of a system per se.

4.1 Most used frameworks for acceptance of driver support systems

There are a few frameworks within which one may understand acceptance in the driver support system literature. The National Highway Traffic Safety Administration (NHTSA) strategic plan, 1997-2002, stated that driver acceptance should be understood in terms of ease of use, ease of learning, adaptation and perception (Najm et al. 2006). These aspects of driver support systems should show whether the system satisfies the needs and requirements of the drivers (our second definition category, chapter 3.1). In 2001, the framework was revised to include ease of use, ease of learning, perceived value, driving performance and advocacy of the system or willingness to endorse it (Sterns et al., 2002 and Najm et al., 2006). Regan et al. (2002) state that acceptability is dependent on usefulness, ease of use, effectiveness, affordability and social acceptability (this is also how the authors define acceptance). When studying ISA, Molin and Brookhuis (2007) showed, by means of a Structural Equation Model (SEM), that acceptability of the system was related to "belief that speed causes accidents", whether the system can "contribute to personal or societal goals" and "if one prefers an ever limiting ISA". The authors did not define acceptance; nevertheless, it was measured by the indicators "intention to buy ISA if it is for free", "wants to possess ISA" and "support for policy to impose ISA on all cars". These indicators do not clearly fit into any of the five definition categories described in chapter 3.1. However, the first two indicators suggest an acceptance definition in category 4

(willingness to use) and the third indicator might be connected to categories 2 or 3 (needs and requirements or sum of attitudes) (compare the discussion regarding the connection between measurements and definitions in chapter 3.3.2).

Neither Najm et al. (2006) nor Regan et al. (2002) have shown if and how these aspects influence the acceptance of a system. This limits the use of these frameworks for understanding how acceptance is formed and how to affect it. The causal model regarding acceptance of ISA described by Molin and Brookhuis (2007) is interesting, and points to the importance of the perceived usefulness of the system, but it is too specialized to describe what stimulates acceptance in a wider perspective. In conclusion, there is a need for a model to satisfactorily describe what influences acceptance vis-à-vis driver support systems.

4.2 Acceptance models within the area of information technology

Following the rapid development of new technologies and software in computer science, interest in the acceptance and use of these technologies has increased significantly. A number of different models are used in the information technology area, which today includes one of the most comprehensive research bodies on acceptance and use of new technology. However, the scientist is faced with a choice of numerous models, for example:

- The Pleasure, Arousal and Dominance paradigm (Mehrabian & Russell, 1974)
- **Theory of Reasoned Action** (Ajzen & Fishbein, 1980)
- Expectation Disconfirmation theory (Oliver 1980)
- Social Exchange Theory (Kelley, 1979, Emersson, 1987)
- **Technology Acceptance Model** (TAM) (Davis, 1989)
- **Theory of Planned Behaviour** (TPB) (Ajzen, 1991)
- **the Model of PC Utilization** (Thompson et al., 1991)
- Social Influence Model (Fulk, et al., 1990 and Fulk, 1993)
- **Motivational Model** (Davis, et al., 1992)
- **A combined model of TAM and TPB** (Taylor and Todd, 1995)
- **Social Cognitive Theory** (Compeau & Higgins, 1995)
- **Innovation Diffusion Theory** (Rogers, 1995)
- Task technology fit (Goodhue & Thompson, 1995)
- System Implementation (Clegg, 2000)
- Technology Readiness (Parasuraman, 2000)
- IS Continuance (Bhattachrjee, 2001)
- Three-Tier Use Model (Liaw et al., 2006)
- Motivation variable of LGO (Saadé, 2007)
- Social Identity Theory (e.g. Yang et al., 2007)

In 2003, Venkatesh et al. integrated eight of the most significant models of individual acceptance (in bold in the list above) into one comprehensive model. The Unified Theory of Acceptance and Use of Technology (UTAUT) is based on an extensive literature review and empirical comparison of the *Theory of Reasoned Action*, the *Technology Acceptance Model*, the *Theory of Planned Behaviour,* a model *combining the Technology Acceptance Model and the Theory of Planned Behaviour*, the *Model of PC Utilization*, the *Motivational Model*, the *Social Cognitive Theory* and the *Innovation Diffusion Theory*, including their extensions (for references see Venkatesh et al., 2003). The key element in all these models is the behaviour, i.e. use of the new technology. The model was validated for acceptance and use of computer software by workers in the USA. The UTAUT model outperformed the eight individual models, accounting for 70 percent of the variance (adjusted R^2) in use (Ventkatesh et al., 2003). The authors concluded that the promising results indicate that the UTAUT is a useful tool for assessing the likelihood of success for new technology introduction and provides knowledge of what stimulates acceptance, which may be used to proactively design interventions (including training, marketing, etc) targeted at populations of users that may be less inclined to adopt and use new systems (Venkatesh et al., 2003).

4.3 The Unified Theory of Acceptance and Use of Technology

Venkatesh et al. (2003) postulate two direct determinants of use: 'intention to use' and 'facilitating conditions'. 'Intention to use' is in turn influenced by 'performance expectancy', 'effort expectancy' and 'social influence'. Gender, age, experience and voluntariness of use act as moderators, see Figure 4.

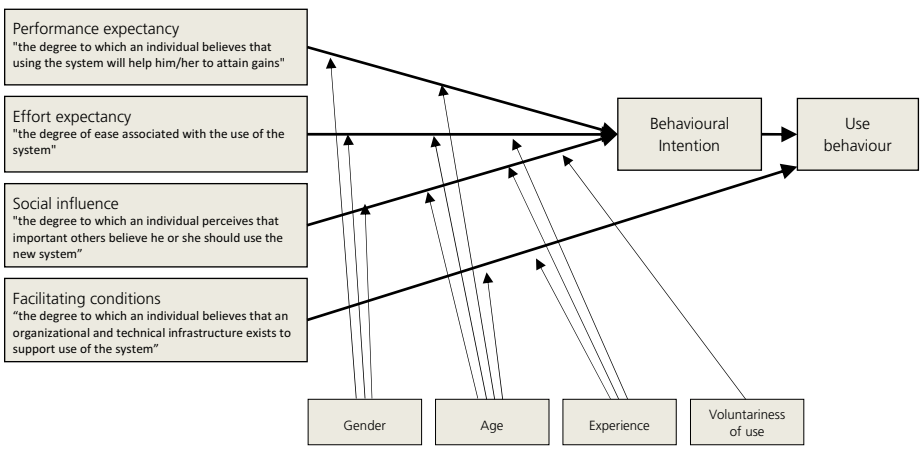

Figure 4: The Unified Theory of Acceptance and Use of Technology and definitions of the constructs (Venkatesh et al., 2003).

The items used in assessing the constructs were also selected from the eight investigated models. Through empirical evaluation, the four most significant items for each construct were chosen as indicators for the constructs in the UTAUT model, see Table 2. The intention to use was assessed through three items and use was measured as duration of use via system logs (Venkatesh et al., 2003).

Table 2: The original UTAUT items used to assess the constructs (Answers were given on a seven-graded scale from "strongly disagree" (1) to "strongly agree" (7)) (Venkatesh et al., 2003).

Performance expectancy
I would find the system useful in my job
Using the system enables me to accomplish tasks more quickly
Using the system increases my productivity
If I use the system, I will increase my chances of getting a raise
Effort expectancy
My interaction with the system would be clear and understandable
It would be easy for me to become skilful at using the system
I would find the system easy to use
Learning to operate the system is easy for me
Social influence
People who influence my behaviour would think that I should use the system
People who are important to me would think that I should use the system
The senior management of this business has been helpful in the use of the system
In general, the organization has supported the use of the system
Facilitating conditions
I have the resources necessary to use the system
I have the knowledge necessary to use the system
The system is not compatible with other systems I use
A specific person (or group) is available for assistance with system difficulties
Intention to use
I intend to use the system in the next <n> months
I predict I would use the system in the next <n> months
I plan to use the system in the next <n> months

Venkatesh et al. (2003) found that 'performance expectancy' is a determinant of 'intention to use' in most situations. The strength of the relationship, however, is moderated by age and gender, being more significant for men and younger workers. The effect of 'effort expectancy' is also moderated by gender and age, being more significant for women and older workers. This effect decreases with experience. The effect of 'social influence' on intention to use is conditioned by

age, gender, experience and voluntariness such that the authors found it to be non-significant when the data were analyzed without the inclusion of moderators. The effect of 'facilitating conditions' is only significant when examined in combination with the moderating effects of age and experience – i.e. they only matter for older workers in later stages of experience (Venkatesh et al., 2003).

4.3.1 The use of the UTAUT model in other areas

The UTAUT model has also been utilized in other areas such as adoption of mobile services among consumers (Carlsson et al., 2006) and in the health sector to examine e.g. the viability of motes (tiny, wireless sensor devices) as health monitoring tools, health professionals' reluctance to accept and utilise information and communication technologies, physicians' acceptance of a pharmacokinetics-based clinical decision support system and physician adoption of electronic medical records technology (e.g. Lubrin et al., 2006; Chang et al., 2007; Hennington & Janz, 2007 and Schaper & Pervan, 2007).

The studies largely support the appropriateness of the UTAUT model in these areas. However, the social influence was not found to be as strong a predictor as suggested by the model when investigating information/communication technologies and decision support in the health sector (Chang et al., 2007 and Schaper & Pervan, 2007). Extensions/modifications of the model were recommended both in the adoption of mobile services and within the health sector (Carlsson et al., 2006; and Lubrin et al., 2006).

4.4 Using the UTAUT model in the context of driver support systems

The Unified Theory of Acceptance and Use of Technology has provided assistance in understanding what factors either enable or hinder technology acceptance and use. It is based on a number of significant behavioural models, of which some are frequently used in traffic safety research as well. Although the model was developed for the information technology area, it has fruitfully been used in other areas. As such, it is possible that the UTAUT model could be useful for understanding and analysing acceptance in the driver support area. A first proposal to use the UTAUT model for acceptance of driver support systems was made by Adell in 2007 (Adell, 2007), but the model has not yet been applied to driver support systems. Although there are many similarities between information technology (IT) and driver support systems, there are also several important differences.

4.4.1 Differences between IT and driver support systems

Applications of information technology and driver support systems share many important features: the user interacts with a technology that is often too complex to fully understand, new applications are incorporated in an existing interaction between the user and the technology, the information conveyed to the user seeks to facilitate an ongoing task, etc.

Despite the similarities, there are important differences between the settings in which information technology applications and the driver support systems are used, particularly at the operational level. One important difference between computer use and car driving is the *time* aspect. When using a computer, the user normally has the possibility of pausing and pondering and even asking for *help* with a process or decision. A continuous decision making or execution is not usually required. It is different when driving a car. The car driver normally has a short time span in which a decision (and action) has to be made and does not normally have the possibility of acquiring assistance with a process or decision. Car driving also demands continuous decision making and execution of these. When using a computer the user does not normally have to *interact* with other humans, while a car driver must interact with other road users, making the social dimension of the two settings very different. When a computer user makes a *mistake* it is often reparable; the consequence is usually irritating and sometimes time consuming, but seldom dangerous. When a car driver makes a mistake it could end in severe physical damage or fatality both for the user and others. The working *environment* when using a computer is imaginary, while the use of a car takes place in the real world.

These differences are important to recognize and address – but they should not stand in the way of transferring methodology from analysing acceptance and use of information technology to studies of driver support systems.

4.4.2 Using the UTAUT for a driver support system – a pilot test

Based on the acceptance research of information technology, a pilot test, using the Unified Theory of Acceptance and Use of Technology (UTAUT), was carried out on a driver support system in 2008. Data for this pilot test was collected in 2006 and 2007 during field trials to evaluate a prototype driver support system (SASPENCE). The purpose was to explore the potential of using the model in the context of driver support systems; thus, the original model was applied as far as possible. However, the experimental design of the field trials could not be modified for the evaluation of UTAUT. Nevertheless, additional questions to the already planned questionnaires allowed data collection for examination of the inter-relationships of '*performance expectancy*', '*effort expectancy*', '*social influence*'

and '*intention to use*', including gender and age as moderators. A summary of the trial is given below; more details about the trial are reported in *paper IV* and Adell et al. (2009).

The SASPENCE system

The SASPENCE system is a driver support system which assists the driver to keep a safe speed (according to road and traffic conditions) and a safe distance to the vehicle ahead. The "Safe Speed and Safe Distance" function informs/warns the driver when a) the car is too close to the vehicle in front, b) a collision is likely due to a positive relative speed, c) the speed is too high considering the road layout and d) the car is exceeding the speed limit.

The driver receives information and feedback from the system by means of an external speedometer display located on the instrument panel, haptic feedback in the accelerator pedal or in the seat belt and an auditory message when a too short headway could lead to imminent danger. For further information about the system see Adell et al. (2009).

Method

Two different test routes were used, one in Turin, Italy, and one in Valladolid, Spain. Both routes were approximately 50 km long and contained both urban and rural road stretches and a motorway section. The test drivers drove the test route twice, once with the system on and once with the system off, thus serving as their own controls. The order of driving was altered to minimize bias due to learning effects.

At each site, 20 randomly selected inhabitants, balanced according to age and gender, participated in the trial. Unfortunately, the data for one test driver was lost due to system failure in Italy, and one of the test drives in Spain was cancelled for safety reasons.

Before the drivers used the SASPENCE system, they were given a brief explanation of the system. The questions regarding the UTAUT assessment were given to the drivers as part of the questionnaire after the second drive.

The items for assessing 'behavioural intention', 'performance expectancy', 'effort expectancy' and 'social influence' were adopted from Venkatesh et al. (2003). Some of the items had to be adapted to fit the context of driver assistance systems, see Table 3. Each item was measured using a seven-point scale, ranging from "strongly disagree" (1) to "strongly agree" (7) (identical to Venkatesh et al., 2003).

Table 3: The original UTAUT items and the modified items used in this study to assess acceptance of driver support systems.

	Original items (Venkatesh et al., 2003)	**Modified items**
Behavioural intention to use the system (BI):		
		Imagine that the system was on the market and you could get the system in you own car.
BI1	I intend to use the system in the next <n> months	I *would* intend to use the system in the next 6 months
BI2	I predict I would use the system in the next <n> months	I *would* predict I would use the system in the next 6 months
BI3	I plan to use the system in the next <n> months	I *would* plan to use the system in the next 6 months
Performance expectancy (PE):		
PE1	I would find the system useful in my job	I would find the system useful in my *driving*
PE2	Using the system enables me to accomplish tasks more quickly	Using the system enables me to *react to the situation more quickly*
PE3	Using the system increases my productivity	Using the system increases my *driving performance*
PE4	If I use the system, I will increase my chances of getting a raise	If I use the system, I will *decrease my risk of being involved in an accident*
Effort expectancy (EE):		
EE1	My interaction with the system would be clear and understandable	My interaction with the system would be clear and understandable
EE2	It would be easy for me to become skilful at using the system	It would be easy for me to become skilful at using the system
EE3	I would find the system easy to use	I would find the system easy to use
EE4	Learning to operate the system is easy for me	Learning to operate the system is easy for me
Social influence (SI):		
		Imagine that the system was on the market and you could get the system in you own car.
SI1	People who influence my behaviour would think that I should use the system	People who influence my behaviour would think that I should use the system
SI2	People who are important to me would think that I should use the system	People who are important to me would think that I should use the system
SI3	The senior management of this business has been helpful in the use of the system	The *authority would be* helpful in the use of the system
SI4	In general, the organization has supported the use of the system	In general, the *authority would* support the use of the system

Results

Factor analysis confirmed on the whole the similarity of the items within the four constructs ('behavioural intention to use the system' (BI), 'performance expectancy' (PE), 'effort expectancy' (EE) and 'social influence' (SI)). However, items PE3 and PE4 did not show high loadings on performance expectancy, see Table 4. Item PE3 showed more resemblance to social influence while item PE4 did not show any clear resemblance to any of the four constructs. One explanation for this might be that the transformation of items PE3 and PE4 from the context

of IT to driver support system brought about a different meaning. Together with the low loadings on 'performance expectancy', it was decided to exclude both these items from further analysis, which increased the content validity. The remaining items were represented by four summated scale variables (averages of item scores).

Table 4: Factor analysis of the modified items comprising the constructs in the UTAUT model

Factor/Variable	Component			
	1	2	3	4
BI 1			0.590	
BI 2			0.926	
BI 3			0.887	
PE 1				0.737
PE 2				0.908
PE 3	*0.858*	*0.044*	*0.124*	**0.261**
PE 4	*0.433*	*0.265*	*0.372*	**0.390**
EE 1		0.659		
EE 2		0.716		
EE 3		0.917		
EE 4		0.866		
SI 1	0.693			
SI 2	0.723			
SI 3	0.687			
SI 4	0.736			

Extraction method: principal component analysis, Varimax-rotation, 4 components extracted.

The internal consistency reliabilities of the summated scale variables were tested with Cronbach's Alpha coefficient (α), which, according to Nunally and Bernstein (1994), should be above 0.70 to reliably measure a single latent construct. All the constructs (PE3 and PE4 excluded) demonstrated an internal consistency higher than 0.70.

The relationships between the independent constructs (PE, EE, SI) and intention to use the SASPENCE system (BI) were examined by applying linear regression analysis. First, the unadjusted effects, i.e. crude effects (meaning that there was only one independent variable in the model) and then the adjusted effects of variables (by simultaneously entering other independent variables into the model) were analysed. The results obtained by the analyses are shown in Table 5.

Table 5: Effects of independent variables on the dependent variable 'behavioural intention' (BI), based on linear regression models

Independent variable in the model	Coefficient ($\beta_{standardized}$)	p-value	$R^2_{adjusted}$	Model
Performance expectancy				
PE	0.41**	0.011	0.15	BI = a + β*PE
PE, EE	0.38**	0.025	0.13	BI = a + β *PE + c*EE
PE, SI	0.37**	0.015	0.22	BI = a + β *PE + c*SI
PE, EE, SI	0.36**	0.027	0.20	BI = a + β *PE + c*EE + d*SI
Effort expectancy				
EE	0.22	0.186	0.02	BI = a + β *EE
EE, PE	0.10	0.522	0.13	BI = a + β *EE + c*PE
EE, SI	0.16	0.306	0.10	BI = a + β *EE + c*SI
EE, PE, SI	0.06	0.704	0.20	BI = a + β *EE + c*PE + d*SI
Social influence				
SI	0.35**	0.030	0.10	BI = a + β *SI
SI, PE	0.31**	0.042	0.22	BI = a + β *SI + c*PE
SI, EE	0.32**	0.048	0.10	BI = a + β *SI + c*EE
SI, PE, EE	0.30*	0.053	0.20	BI = a + β *SI + c*PE + d*EE

PE: performance expectancy, EE: effort expectancy, SI: social influence
** $p<0.05$
* $p<0.10$

'Performance expectancy', i.e., the expected benefits gained by using the system, had a significant positive effect on intention to use the system. It had a significant crude effect, and only small changes in the coefficient of determination were observed when other independent variables (EE and SI) were added to the model.

The same pattern was observed for 'social influence', which also demonstrated a significant positive crude effect on intention to use the system and only small changes in the coefficient of determination when the other independent variables (PE and EE) were added to the model.

However, 'effort expectancy' showed no significant direct relation to intention to use the system. No significant effects could be found together with 'performance expectancy' and 'social influence'. Further, when including the effort expectancy in the model, the adjusted explanatory power decreased.

The explanatory power of the UTAUT model for intention to use the SASPENCE system (BI) was 20 % when all independent variables were included (PE, EE and SI). 'Performance expectancy' (PE) and 'social influence' (SI) had a significant impact on 'behavioural intention' (BI). The standardised beta coefficient revealed that the impact of 'performance expectancy' was slightly more significant than that

of 'social influence'. In this data material the 'effort expectancy' (EE) did not show any correlations to 'behavioural intention'. The results of the tested model are summarized in Figure 5.

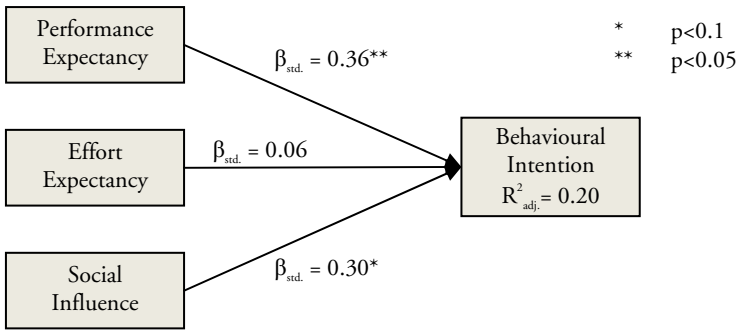

Figure 5: Regression coefficients and explanatory power for the UTAUT model when applied to acceptance of the driver support system SASPENCE.

The inclusion of the moderators 'gender' and 'age' did not affect the results, regardless of whether 'effort expectancy' was included in the analysis or not.

4.4.3 Further analysis of the individual items in the UTAUT-model

The relatively low explanatory power of the UTAUT-model in the pilot test leads us to further investigate the significance of the individual items comprising the constructs used in the model.

When examining the correlation between the items included in the constructs 'performance expectancy', 'effort expectancy' and 'social influence' on the one hand, and 'behavioural intention' on the other, some items stand out as more influential compared to others. The independent items used, PE1, PE3, PE4 and SI2 stand out with statistically significant regression coefficients ($p<0.05$) of about 0.4 or more and with an explanatory power above 10 %, see Table 6. This indicates that the "translated" items PE3 and PE4 are important for the 'behavioural intention' even though they are not good indicators of 'performance expectancy' (as shown by the factor analysis presented in Table 4).

Table 6: Effects of the independent items on the dependent variable 'behavioural intention' (BI), based on linear regression models.

Independent variable in the model	Coefficient ($\beta_{standardized}$)	p-value	$R^2_{adjusted}$	Model
PE1 (useful)	0.531**	0.010	0.262	BI = a + β * PE1
PE2 (quick reactions)	0.233	0.159	0.028	BI = a + β * PE2
PE3 (driving performance)	0.391**	0.015	0.129	BI = a + β * PE3
PE4 (accident risk)	0.476**	0.003	0.205	BI = a + β * PE4
EE1 (clear interaction)	0.216	0.193	0.020	BI = a + β * EE1
EE2 (easy to become skilful)	0.174	0.295	0.004	BI = a + β * EE2
EE3 (easy to use)	0.100	0.550	-0.018	BI = a + β * EE3
EE4 (easy to operate)	0.202	0.224	0.014	BI = a + β * EE4
SI1 (influencing people)	0.256	0.120	0.040	BI = a + β * SI1
SI2 (important people)	0.412**	0.010	0.147	BI = a + β * SI2
SI3 (helpful authority)	0.181	0.278	0.006	BI = a + β * SI3
SI4 (supporting authority)	0.182	0.275	0.006	BI = a + β * SI4

PE: Performance Expectancy; EE: Effort Expectancy; SI: Social Influence; BI: Behavioural Intention
** $p<0.05$

The items PE1, PE3, PE4 and SI2, combined into one model to explain 'behavioural intention', were able to account for about 30 percent of the variance in 'behavioural intention'. The items PE3 and PE4 showed small, statistically insignificant, regression coefficients (0.03 and 0.17, respectively). When using backwards elimination, PE4 (accident risk) and PE3 (driving performance) were excluded from the model, indicating that the explanation provided by PE3 and PE4 could be provided by the items PE1 and SI2. The fact that PE3 shares similarities with SI2 and that PE4 shares similarities with PE1 and SI2 has also been shown in the factor analysis, see Table 4.

The model including PE1 and SI2 explains about 33 % of the variance in the dependent variable 'behavioural intention' and the regression coefficients of PE1 and SI2 are 0.46 (p=0.003) and 0.30 (p=0.042) respectively. This is a higher explanatory power compared to the model including the constructs, indicating that some of the items comprising the constructs are more important than the constructs themselves. This suggests two things: firstly, one has to remember that these results are based only on the data collected in the pilot test. In another trial other items may stand out as more important. In the long run, using more items to assess a construct, compared to a single item, is likely to be more robust. Secondly, the results emphasise the need to identify items that can assess the "essence" of the constructs in a driver support system perspective. This work should continue.

5 Discussion

"It is unproductive to invest effort in designing and building an intelligent co-driver if the system is never switched on, or even disabled".

Van der Laan et al. (1997)

Information on the drivers' experiences and acceptance of these systems is of paramount importance for assessing the true traffic safety effects of driver support systems. To gain this information, the extended objective of this thesis has been, besides investigating driver experiences with ISA, to examine the concept of acceptance of driver support systems and how the drivers' experiences of such systems influence acceptance.

5.1 Thesis contribution

A definition of acceptance

Good academic practice emphasises the importance of being clear and distinct to minimize ambiguity and to facilitate comprehension and revision of the scientific work presented. However, in ITS research the definition of 'acceptance' is usually taken for granted and most researchers assess acceptance without defining it. This is one of the fundamental problems in acceptance research today. The different ways of measuring acceptance makes comparisons between different studies and different systems difficult.

The proposed acceptance definition postulates that acceptance is *"the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving"*. This definition stresses the importance of a user-centred view and has the advantage of both considering the intention to use and emphasising the importance of manifesting the intention to use the system in actual behaviour. By this definition a driver does not have to like to use the system to demonstrate acceptance. It is enough that he/she 'tolerates' its use. The definition also implies that there are different degrees of acceptance, and that it is not limited to acceptance/no acceptance but is of a more continuous nature. The degree of acceptance could also be zero of course.

An acceptance model

There is a need for a model describing the various factors that may influence the acceptance of driver support systems. The most extensive research bodies on the acceptance and use of new technology are found today in the information technology area, where a number of different acceptance models are used. The Unified Theory of Acceptance and Use of Technology (UTAUT) model has been deemed interesting to apply to the context of driver support systems in this thesis since it summarises eight of the most significant models applied in the information

technology area, and has already been used in other contexts outside information technology. Hence, the UTAUT model is presented as a base for examining what influences acceptance of driver support systems.

According to the model 'use behaviour' is influenced by 'intention to use' and 'facilitating conditions'. 'Intention to use' is in turn influenced by 'performance expectancy', 'effort expectancy' and 'social influence'. Gender, age, experience and voluntariness of use act as moderators.

A pilot test of the UTAUT model in the context of driver support systems

Inter-relationships of 'performance expectancy', 'effort expectancy', 'social influence' and 'intention to use', using age and gender as moderators, were examined in the pilot test. Due to experimental constraints, the 'use behaviour', 'facilitating conditions' and the moderators 'experiences' and 'voluntariness of use' could not be included.

The results from the pilot test supported to some extent the use of UTAUT as a framework to assess acceptance of a driver support system, but the explanatory power of the model was only twenty percent. Both 'performance expectancy' and 'social influence' indicated a relationship with the drivers' intention to use the system. 'Performance expectancy' was found to be the strongest predictor of the intention to use the system. This is consistent with earlier findings, where, for example, Venkatesh et al. (2003) and Chang et al. (2007) have shown that 'performance expectancy' is a major predictor of 'behavioural intention'. However, those studies have also shown that 'effort expectancy' is a stronger predictor of 'behavioural intention' than 'social influence', which was not confirmed in the pilot test.

The pilot test highlighted the importance of 'social influence' for 'behavioural intention' but did not verify the significance of 'effort expectancy'. This may be a consequence of the small amount of data that was available for the pilot test, or due to improper assessment of the construct in the context of driver support systems. However, the context of computer use, for which the UTAUT model was developed, differs from the context of using driver support systems (driving). Driving demands interactions with other road users and is therefore by its nature a task with a strong social dimension. The importance of 'social influence' as a predictor of 'behavioural intention' in the context of a driver support system could be a consequence of this. Further, the effort associated with the use of e.g. a computer program and the use of a driver support system may be different. Employing a computer program normally demands actions by the user, while a driver support system normally runs without requiring input from the driver, informing/warning the driver only when there is a need to do so.

Further analysis of the items comprising the independent variables suggested that individual items used in assessing the constructs were better predictors of 'behavioural intention' than the constructs themselves. The items 'usefulness' (PE1), 'driving performance' (PE3), 'accident risk' (PE4) and 'important people' (SI2) had significant crude effects on 'behavioural intention', 'usefulness' and 'accident risk' with a higher explanatory power than the whole model. The significant crude effects of the items 'driving performance' and 'accident risk' (excluded from the pilot test of the UTAUT model through factor analysis) indicated that they, although not clearly belonging to the construct 'performance expectancy', touch important aspects when explaining the 'behavioural intention' of using a system. Still, there seemed to be a considerable overlap between these items and the items 'usefulness' and 'important people'. When combining these items in one model and using backwards elimination, only the items 'usefulness' and 'important people' were left in the model. This model explained more than the originally tested model, which used the constructs 'performance expectancy', 'effort expectancy' and 'social influence' to explain 'behavioural intention'.

Proposed modifications to the model

On the basis of the results from *papers I, II, III and IV*, thee modifications to the model are suggested: 1) Adding a new construct to the model to include the emotional reactions of the driver, such as driving enjoyment, irritation, stress, feeling of being controlled, image etc. 2) weighing the constructs by their perceived importance, and 3) including reliability issues in the model. The modifications 1 and 2 are illustrated in Figure 6, further research is needed on how system reliability should be included in the model.

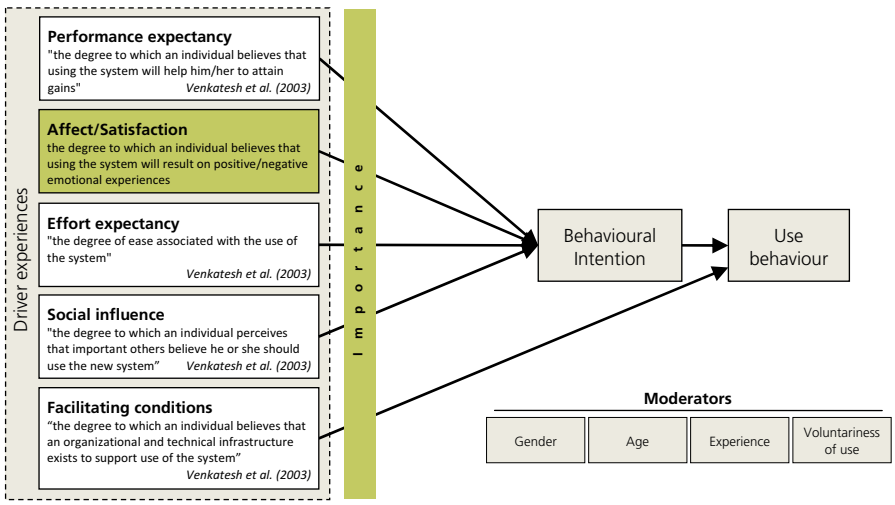

Figure 6: The proposed acceptance model, including two of the suggested modifications to the UTAUT when applied to driver support system, in green.

The results from *papers I, II and III* show that most drivers seem to experience the effects of using the system in a similar way (e.g. risk of being fined for speeding, speed change, travel time, traffic safety). The differences between the test drivers are mostly to be found in emotional experiences, workload and usefulness of and satisfaction with the system. This suggests that there is some difference between the effects related to driving outcome and emotion-related effects.

The original UTAUT model does not include the emotional reactions by the user. Our results clearly show emotional reactions from the drivers when using the system. It is plausible that including emotional experiences, such as driving enjoyment, irritation, stress etc. in the model would improve it. This way of differentiating between more rational aspects and more emotional aspects is in line with the procedure suggested by van der Laan et al. (1997), which identifies usefulness and satisfaction as two dimensions of acceptance.

The pilot test indicated that 'effort expectancy' did not influence 'behavioural intention'. However, the results from *papers I* and *III* show that the use of the ISA-system influences some aspects of the self-reported workload. Therefore moderating the items that assess "effort expectancy" to fit the context of driver support systems is to be preferred to removing the construct from the model.

A driver might experience both positive and negative effects during the use of a system, and whether he/she in the end would like to continue to use the system depends on a trade-off between these effects. In *paper II* a relatively low willingness to keep the system was reported even though many positive experiences had been reported (high usefulness, increased performance as a driver, increased safety and reduced risk of getting speeding tickets). The reason for this could be either that the aspects of negative experiences (low satisfaction, increased emotional pressure and the perceived longer travel time) were more important (or above an acceptable threshold) or that the aspects of positive experiences were not so important to the driver.

The trade-off between the different aspects is not the same for all drivers, but depends on how important the aspects are to the individual driver. The "safety conscious" driver may, for example, value the perception of increased safety very highly and disregard the perception of increased travel time, while the "freedom driver" may value the feeling of freedom and driving enjoyment highly and attach lower importance to other factors. This is in line with e.g. the expectancy-value theory (see e.g. Ajzen & Fishbein, 2008). It is possible that such an extension may improve the model, but further research has to show whether this is true and how it should be performed.

Issues related to system reliability are not included in the original UTAUT model. The results in *papers I* and *II* illustrate, however, how fundamental the reliability of the system is to the drivers. Reliability is a pressing issue when working with newly developed or prototype systems and should not be neglected. Therefore, it is proposed that this aspect be included in the model. Further research is needed to investigate how this should be done.

Neither of the moderators 'age' and 'gender', which were included in the pilot test of UTAUT, influenced the results. The moderators 'experience' and 'voluntariness of use' could not be included in the UTAUT pilot test due to experimental constraints. However, the results from *papers I and II* show some differences in experiences between age groups and gender. It is therefore too early to exclude them from the model. Further, the results from *paper I* show that the time the system had been used influenced the drivers' experiences with the system. It is therefore likely that 'experience' might also become an important moderator in the context of driver support systems. Additionally, these results refer to two different levels of experience; drivers with no experiences of a system might still have a lot of expectations of how it would be to use the system. It is reasonable to think that whether the system can live up to these expectations is of vital importance for its acceptance. The moderator 'voluntariness of use' has implications for both system design and implementation of the system. It is known that the more intrusive a system is, the less it is liked (Vägverket, 2002; Rook & Hogema 2005). Therefore it is likely that the moderator will also be important in the context of driver support systems. Which of the constructs the moderators affect, and how, has to be investigated. Results from *paper I* suggest, for example, that 'experiences' also moderate 'performance expectancy', which is not suggested by the UTAUT model.

Implications for ISA-implementation

The drivers' subjective evaluation of their risk of being fined for speeding decreased more than their impression of their safety increased, which has implications for the implementation of ISA systems. The incentive to get the drivers to use the systems might not be the argument that they can increase their safety by using ISA (which is the reason behind the societal push for ISA), but the money and embarrassment saved by avoiding speeding tickets, which in its turn depends on the level of speed limit enforcement. Nonetheless, to succeed with voluntary implementation, drivers have to recognise some personal benefit of using the system large enough to put up with the increased feeling of irritation and longer travel times. If this is not the case, voluntary implementation has to rely on drivers' will to act for a collective good.

5.2 Methodology discussion

The importance of adaptation period in effect assessment

The findings from the large-scale field trial showed that the time a system had been used influenced the drivers' behaviour (Várhelyi et al., 2004) and experiences with the system (*paper I*), and hence it is important to be considered when evaluating the effects of driver support systems. The results from the questionnaires showed that the drivers' experiences of their speed changes, self appraised driving performance, driving enjoyment and stress changed between the short and long-term measurements. There is still a major question though: how long does the adaptation to new driver support systems take? The results clearly showed that the adaptation was still ongoing after one month. However, is it necessary to wait 6 to 12 month to investigate long-lasting effects or can they be assessed earlier? Or is the adaptation process even longer? Research evaluating major reconstructions of the traffic environment suggests that the adaptation period is longer than one month and may be as long as four to five months (Hydén & Várhelyi, 2000). The length of the adaptation period for driver support systems is not known. Unfortunately, long-term field trials are very costly and rare, which makes it hard to learn more about the adaptation process.

Transferability of results

The large similarities in the experiences of Swedish, Hungarian and Spanish drivers are noteworthy, indicating that the effects experienced in one region may also be valid for other European regions. This is of major consequence when interpreting research findings. However, there are reasons to be cautious. The results indicate some differences too, particularly regarding subjective workload. Besides, driver experiences have been examined in European countries. Even though there are differences between the countries (regarding laws, road environment, enforcement, driving style etc.), there are substantial similarities within Europe compared to other continents; whether drivers respond similarly in other parts of the world remains to be explored. Further, the long-term trial in Sweden demonstrated that the process of adapting to a new driver support system was still ongoing after one month of usage (the length of the field trials in Hungary and Spain). From that perspective, it is possible that the "final" long-term driver behaviour and experiences in the three regions will be less similar.

Test-driver selection bias

When interpreting the results, one must bear in mind that there is a possible selection bias in them. The test drivers in Hungary and Spain were all recruited by either accepting an offer of participation from their garage or by responding to ads in the newspapers. No particular effort was made to persuade drivers with a negative attitude towards the system to participate in the trial. Hence, the general

opinion of the driver population of the country could be more negative to the system than the participating drivers indicate. However, the results of these trials are very much in line with the results of the large-scale trial in Sweden, where considerable efforts were made to include drivers with an initial negative attitude towards the AAP-system (*paper I and II*). On the other hand, also in that trial, the majority of the test drivers were positive towards the system. This fact highlights a methodological problem that is not easy to solve. It is not possible to force drivers to participate.

Assessing constructs

The analysis in *paper IV* showed a methodological problem with the "translation" of the items, which were used in information technology to assess constructs in the UTAUT model, into the area of driver support systems. The items used were adopted from Venkatesh et al. (2003) as closely as possible. However, for two of them ('Using the system increases my productivity', and 'If I use the system, I will increase my chances of getting a raise') it did not make sense to keep the original wording in the context of a driver support system. These two items also showed validity problems and were excluded from the analysis after the factor analysis.

In the pilot test, the item 'Using the system increases my productivity' was replaced by 'Using the system increases my driving performance'. This appeared to be a too vague concept and the factor analysis indicated more resemblance with 'social influence' than with 'performance expectancy'. It is possible that performance expectancy is better assessed through more direct transportation-related effects like travel time and fuel consumption. The item 'If I use the system, I will increase my chances of getting a raise' was translated into 'If I use the system, I will decrease my risk of being involved in an accident'. These two items have at least one major difference; while the original item speaks of a reward (raise), the modified item speaks of a lack of negative consequence (accidents). There are seldom rewards given for desired driving behaviour. The analysis implies that traffic safety (absence of accidents) is related to all four constructs ('performance expectancy', 'effort expectancy', 'social influence' and 'intention to use'). This is likely to have its roots in its fundamental importance for the driver, the people around the driver, and the authority. It is possible that items dealing with avoiding fines or self appraised rewards, such as enjoyment, comfort, image etc, may be more specifically related to this dimension of 'performance expectancy'.

The results indicate the need to investigate whether the items capture the 'essence' of the constructs when applied to driver support systems, both when "translations" of the items are needed and when not needed. It seems that some of the items are relevant, and that other items are 'polluting' the constructs with irrelevant

information. The transformation of questions from one context to another is always problematic. What is an appropriate assessment of a construct in one context might be unsuitable, wrong or irrelevant in another, depending on the characteristics of the area. However, it is important to remember that these results are based on one, quite small, data sample. It is possible that the results might be different in another data set, suggesting other items to be the most relevant. A construct, assessed by several items, is therefore likely to be more robust than using single questions when modelling acceptance. The work on identifying and assessing the constructs should be continued.

5.3 Conclusions and final remarks

- The proposed acceptance definition postulates that acceptance is *"the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving"*.
- A pilot test supported to some extent the use of the Unified Theory of Acceptance and Use of Technology (UTAUT). Both the constructs 'performance expectancy' and 'social influence' affected the drivers' intention to use the system, but the explanatory power of the model was only twenty percent.
- Three modifications to the model are suggested:
  1. Adding a new construct to assess the emotional reaction of the driver.
  2. Weighing the constructs by their perceived importance.
  3. Including reliability issues in the model.
- The incentive to get the drivers to use an ISA system might not be the argument that they may increase their own safety by using ISA, but the money and embarrassment saved by avoiding speeding tickets.
- The duration a system has been used influences the driver's experiences of it. The 'final' long-term experiences of the system cannot be assessed after one month of usage.

The research in this thesis contributes to the knowledge of how driver speed support systems are experienced by the drivers, particularly regarding long-term effects. It is also expected that the acceptance-related work can strengthen the existing theory regarding acceptance of driver support systems by defining acceptance and by introducing and conducting a pilot test with the Unified Theory of Acceptance and Use of Technology. Nevertheless, research needs to continue to test the modified UTAUT model and to gain further insights into how acceptance should be measured.

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