Speed regulating Effects of Incentive-based Intelligent Speed Adaptation in the short and medium term

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Hastighedsregulerende effekter fra Incitamentbaseret Intelligent Farttilpasning på kort og mellemlang sigt

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I Preface

This PhD thesis has its basis in four published papers and supplements with introductory materials, a literature review and further results. It consists of one peer-reviewed journal paper and three peer-reviewed conference papers with me as main author; and this thesis, which includes a number of sections some of which are at variable degrees ready for later publication.

The thesis has been written at Aalborg University, Denmark in the Traffic Research Group in the Department of Development and Planning. It was written in the period July 2006 to June 2011. I am grateful for all the support I have received from the University, which has greatly enhanced the progress of my work. Likewise, I would very much like to thank the insurance company Foreningen Østifterne for kindly providing financial support for the research project in general.

Many persons have contributed directly or indirectly to the completion of the thesis. Particularly, I wish to thank my supervisor Associate Professor Harry Lahrmann of the Traffic Research Group, Department of Development and Planning at Aalborg University for innumerable meetings, short as well as long. Many of them were as short as a couple of minutes, but they were still very helpful in contributing to the problem solving in progress.

I also wish to thank the rest of the research group involved in Intelligent Speed Adaptation. Thanks to Associate Professor Lisbeth Harms of Copenhagen University for her many inputs, partly to the papers but also to more generic discussions concerning the trial itself and the challenges during the trial period. Furthermore, I wish to thank Associate Professor Jens Juhl of Aalborg University for his very valuable contributions to keeping the speed map updated and for more general discussions on GPS data. I am also much obliged to Master in Psychology Britt Klarborg of Copenhagen University for input and discussions during the first part of the PhD work. Equally, I wish to thank Postgraduate Student, now Master in Engineering Ida Litske Bennedsen for being instrumental in reducing the administrative workload during the trials. I also wish to thank Web-developer Erik Jensen, formerly Aalborg University, currently Roskilde University for his feedback and help in connection with the design of questionnaires and web applications. Also, many thanks to Professor Rasmus Waagepetersen of the Department of Mathematical Sciences and Assistant Professor Jens Christian Overgaard Madsen from the Traffic Research Group at Aalborg University for their help with statistical tests. Moreover, many thanks are given to Research Assistant René Hansen for his help with data queries. Last but not least, I wish to offer my special thanks to PhD candidate Nerius Tradisauskas of Aalborg University for all his help with data queries and the like, but also for many good talks about more general topics - be they work related or not.

The design of the equipment to be installed in the drivers' cars has been carried out by the Danish IT company M-tec. From M-tec I would very much like to thank CEO Svend Hansen; Sales Manager Jørgen Raguse, and Head of Development Poul Heide for their job before and during the trials. Thanks are due to Keld Brun Hansen, Helle Krøyer Hansen, Christian Tangdal and Christina Daub of the Danish insurance company, Topdanmark. They have contributed to keeping the project going as well as supported the recruitment campaign generously.

A stay at a foreign research institution being an integral part of the PhD programme, I went to the *Monash University Accident Research Centre* in Melbourne, Australia. About 100 fantastic days 'down under' during which I learned a lot, concerning Intelligent Speed Adaptation as well as research work in general. In addition to the working approach, we also had a very nice time as a family there, meeting a number of new friends and experiencing a bit of this fantastic country.

At the Monash University Accident Research Centre many colleagues contributed to my thesis through discussions over lunches or when time allowed it - nobody mentioned, nobody forgotten. However, I do wish to mention Professor Tom Triggs, my supervisor, and his wife Tele, who very generously invited us to their home. Also a special thanks to Eve Mitsopoulos-Rubens, who helped us not only with a number of practical issues but also contributed to my thesis through many discussions and proof-reading my papers. Warm thanks are owed to HR Officer Rachel Whitworth for making innumerable arrangements and phone calls and sending mails to prepare a good stay for us. Moreover, we are very grateful that she and her husband Paul showed us a part of Melbourne which we would probably not otherwise have seen. Finally, special thanks are offered to David Healy of the Transport Accident Commission Victoria, currently Monash University Accident Research Centre, for his help with data analyses as well as for many good and bright inputs and discussions.

A number of foundations generously contributed to the trip becoming a successful experience, for which I am very grateful: Knud Højgaards Fond, Otto Mønsteds Fond, Niels Smed Søndergaards Thy-Fond and last but not least the Faculties of Engineering, Science and Medicine of the University of Aalborg.

I also wish to express my thanks to Trilingual Secretary Dorte Nørgaard Madsen, who has been very helpful regarding the administrative procedures before my Australia trip and in particular regarding the administrative procedures in connection with the organization of a PhD course in 2009. Furthermore, I wish to thank PhD Anette Jerup Jørgensen for a lot of discussions concerning road safety in general and for introducing me to a social-science approach to activities related to traffic behaviour. Moreover, I wish to thank Bodil Lyngholt Bloch, who has been most helpful with proofreading. Also many thanks to my other good colleagues in the Traffic Research Group of Aalborg University

for many interesting discussions on all matters of interest. Although somewhat removed from my research area sometimes, some of the more generic discussions have turned out to be of great use to my work. Furthermore, I would like to thank the secretaries Susanne Løøw, Eva Janik, and in particular Lilli Glad for their help to get through the administrative 'jungle' a university can be.

I would also like to offer my thanks to Martin Hellung Larsen of the former Danish Road Safety and Transport Agency, now the Danish Transport Agency for his general support to the project development as well as for several discussions regarding specific areas of research.

Moreover, I wish to apologise to my friends and relatives whom I have not visited, phoned, met or talked to quite as often as I would have liked to.

Last but certainly not least, I sincerely thank my family, who have often felt my absence - maybe not physically - I was only a few steps away in front of my desktop - but certainly mentally. Especially, I thank my beloved wife Anne for showing great patience on many occasions when the work load made me seem endlessly absent, my son Valdemar, who has often asked: 'are you busy now, Dad?', and my little girl Sofie My, who has very often pointed to the office saying 'Daddy'.

June 2011
Niels Agerholm

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III List of Abbreviations

Abbreviation	Full name	Additional information
AAP	Active Accelerator Pedal	A haptic throttle, which vibrates or becomes heavy to depress if the speed limit is violated.
ABS	Anti-lock Braking System	A system, which prevents the wheel from locking up during braking manoeuvres
ADAS	Advanced Driver Assistance Systems	Systems to help the driver during the driving process
BAC	Blood Alcohol Concentration	-
BEEP	BEEP	The notion used for the combination of visual and auditory feedback in the *PROSPER* ISA trial
e-call	in-vehicle emergency call system	System, which automatically can send information to the emergency agencies in the event of an accident
EDR	Event Data Recorder	System, which stores data a short time before, during and after any accident
ESC	Electronic Stability Control	It improves the vehicle stability by detecting and minimizing skids
EU	European Union	-
FCA	Forward Collision Avoidance	A system, which intervene if the headway is too short
FCD	Floating Car Data	Data collected from driving vehicles
FDW	Following Distance Warning	A system, which warn the driver if the headway is too short
FF	Free Flow	Driving without interruptions from other vehicles
FFS	Free Flow Speed	The speed while driving without interruptions
FFSD	Free Flow Standard Deviation	A way to measure speed variation
F/V	Fatalities per vehicle	A way to measure the traffic-risk in a society
GDP	Gross Domestic Product	Gross Domestic Product
GIS	Geographic Information Systems	Systems which work with data linked to locations
GPRS	General Packet Radio Service	Mobile data format
GPS	Global Positioning System	A worldwide covering system for navigation
INFATI	Intelligent Farttilpasning	An older Danish ISA trial and the Danish abbreviation for ISA
ISA	Intelligent Speed Adaptation	ADAS which include feedback to the driver, connected to the driving behaviour and the speed limit

Abbreviation	**Full name**	**Additional information**
ISA C	Intelligent Speed Adaptation Commercial	The Danish ISA trial involving commercial vehicles
ISA UK	ISA UK	A newly finalised English ISA trial
IT	Information Technology	-
ITS	Intelligent Transport Systems	Information technology in connection with transport
IVDR	In-Vehicle Data Recorder	A system collecting driving data including position and/or time
IWGOSC	International Working Group on Speed Control	Network of experts working with ISA and related topics
Key ID	Key Identification	Personal identification handed out to each of the commercial drivers who participated in ISA C
km/h	Kilometre per hour	-
LAVIA	Limiteur s'Adaptant à la VItesse Autorisée	A French ISA project
MFFS	Mean Free Flow Speed	The mean driving speed when the vehicle in front has not affected the driver, i.e. under free flow conditions
mph	Miles per hour	-
OBU	On Board Unit	Unit placed in a vehicle
PAYS	Pay As You Speed	The Danish incentive-based ISA trial Pay As You Speed
PDA	Proportion of the Distance driven Above a set limit	An approach to measure the amount of speed limit violation based on the distance driven
PROSPER	Project for Research On Speed adaptation Policies on European Roads	Two parallel ISA trials in Spain and Hungary
PTA	Proportion of the Time driven Above a set limit	An approach to measure the amount of speed limit violation based on the time driven
SARTRE	Social Attitudes to Road Traffic Risk in Europe	A large-scale European questionnaire-based study regarding the attitude to road traffic risk
SD	Standard Deviation	Standard Deviation
SEK	Swedish Krona	Swedish Currency
SQL	Structured Query Language	A database computer language
TAC	Transport Accident Commission	The Transport Accident Commission of Victoria, Australia
UBI	Usage Based Insurance	Insurance where the premium is based on the use of the car

IV Reading guide

This thesis can be read from beginning to end without much difficulty. In general six main contents can be identified: introduction to speed as a road safety challenge (Section 1); the proposed solution: Intelligent Speed Adaptation (Section 2); research framework (Section 3); methodology considerations (Section 4); results from the Intelligent Speed Adaptation trials (Section 5); and the conclusion of the thesis (Section 6).

References are in Harvard style. In the text a reference is shown in parentheses with surname and year of publication. A complete reference list follows after Section 6.

In Appendix 3 the papers included in this thesis of which I am the main author are to be found. Other papers regarding the two Danish ISA trials have been made to which I have contributed. They are not included in the thesis but are available on http://personprofil.aau.dk/forskning/publikationer/114320?languageId=1. If one decides to read them, it should be borne in mind that many results here are similar to the ones presented in the thesis. The reasons for this are that many of the results are also presented in Danish and that from being technical some papers have become scientific papers.

In reading the thesis one will find many of the central results and considerations made in the papers authored by me. However, to focus the thesis no further considerations are included concerning speed map updating procedures or the attitudes among the drivers participating in one of the ISA trials. The main reasons for these are as follows: 1. the speed map is a premise for ISA and not the direct target set for the project. However, it has been the intention to present sufficient information so as to make the thesis more accessible, and 2. the thesis mainly focuses on how ISA affects driving behaviour, not on the attitude among the drivers involved. The papers should be seen as documentation of where and how the research results have been published more than direct information of interest.

The peer-reviewed journal paper, of which I am the main author is:

Agerholm, N., Waagepetersen, R., Tradisauskas, N., Harms, L. & Lahrmann, H. 2008. Preliminary results from the Intelligent Speed Adaptation project Pay As You Speed. *IET Intelligent Transport Systems*. 2 (2), pp. 143-153.

The peer-reviewed conference papers, of which I am the main author, are:

Agerholm, N., Juhl, J., Sonne, I.B. & Lahrmann, H. 2007. Spar på Farten - opbygning og vedligeholdelse af hastighedskortet (Pay As You Speed - development and maintenance of the speed limit map). *Annual Transport Conference at Aalborg University*, Aalborg, Denmark, 27-28 August 2007, pp. 1-10.

Agerholm, N., Tradisauskas, N., Waagepetersen, R. & Lahrmann, H. 2008. Intelligent Speed Adaptation in Company Vehicles. In IEEE Proceedings, Intelligent Transport Systems. *IEEE Intelligent Vehicles Symposium*, IV 08. Eindhoven, The Netherlands, 4-6 June 2008, pp. 1-8.

Agerholm, N., Tradisauskas, N. & Lahrmann, H. 2009. How Intelligent Speed Adaptation affects company drivers' attitudes to issues related to traffic. *16th ITS World Congress*, Stockholm, 21-25 September 2009, pp. 1-12.

V Summary

There is an urgent need for new approaches to road safety

Despite massive improvements in vehicles' safety equipment, more information and safer road network, inappropriate road safety is still causing one of the greatest loss of life years in the world. In 2004 more than 1.27 million people globally were killed and 50 million injured. Fortunately, increased welfare results in a disconnection between economic growth and increased road risk. In industrialised countries the result has been fewer road accident victims even though the amount of road transportation has continued to increase. Until a few years ago the number of fatalities in most countries had decreased year by year while the amount of traffic increased. However, this trend has been replaced by a more uncertain development towards a constant or even somewhat increasing risk.

Inappropriate speeding and high speed variation are central causes of the high number of fatalities on the roads. The results are clear: the higher the speed, the higher the number of especially fatalities. Moreover, the change in speed affects the number of serious accidents more than the number of minor ones. Also, it is found that higher mean speed results in increased speed variation and that higher speed variation in particular results in higher accident risk. Despite the introduction of speed limits and the subsequently reduced number of fatalities, speed limit violating driving behaviour is still widespread, also in countries with a high road safety level. There is some variation between countries, but it seems that about half of drivers or even more speed on roads outside built-up areas.

Such a substantial amount of speeding can be explained by the fact that in case of speeding, the reward is immediate: reduced transportation time, which most road users appreciate. Hence it is easy for drivers to ignore or repress any speeding-related risk. Also, most people underestimate their speed and what the road condition might allow. Furthermore, in a modern car the feeling of speed is reduced due to e.g. less engine noise and wind resistance. The feeling is also much more secure. Even at high speeds, a modern car feels stable and calm on the road. And this feeling is supported by equipment such as ABS and airbags, which might give the driver a false safety. In addition, many drivers have a feeling of joy when driving at high speeds. Moreover, one might say that traffic is a bad educator. The single trip seems very safe because the average driver would have to drive for several hundred years before he/she would be involved in a police-reported accident causing severe injuries or fatalities.

The introduction of speed limits has, despite the fact that markedly proportions of the road users in most countries violate the speed limits on a large scale, resulted in considerable reduced number of road fatalities. Traditional solutions to prevent speed violations have been enforcement, information, and enhanced road design. Enforcement is a central solution. Involving the risk of drivers getting caught in case of speeding enforcement has considerable effect on the number of speed limit violations. However, it has been found that the effect of enforcement is transient in space as well as in time. Also, the risk of getting penalised for violating the speed limit is low, it seems that the average driver can drive for more than ten years before he/she will get a fine for violating the speed limit. Information is an inexpensive way to reduce speed violation. However, the baseline level upon which a campaign has to build influences the potential level of change considerably. The less speed violation in baseline, the less effect can be expected. Despite the positive effects of campaigns for road safety, it should be noted that information campaigns against speed violations have been carried out for many years - probably with significant effect - but that it is not obvious that further significant effects against speed violations can be achieved. Road design in most industrialised countries is under continuous development towards a safer structure with a view to minimising the number of accidents, and towards a more forgiving structure of the road design in the event of crashes. In general, the locations where the number of accidents is higher than expected - the so-called black spots - are enhanced to eliminate the over-representation of accidents there. It seems to have worked well. However, as the most problematic black spots have been enhanced with a considerable safety benefit, focus has consequently been turned towards the remaining (and less dangerous) spots. In the latter spots, only small safety benefits can be expected. The black spots being in general eliminated, it is hard to gain further safety benefits by improving the road design unless at very high costs. Traffic-calming measures have shown significant safety effects. As for black spot treatment most of the less safe areas have been enhanced, and it seems reasonable to assume that further road safety improvement is difficult to reach without very high costs. Sufficient further road safety seems difficult to achieve by means of the above-mentioned solutions. Additional solutions based on information technology (IT) in vehicles, on the other hand, might further improve the road safety level. The solutions are multifarious and can basically be divided into two groups: passive measures which lead to loss reduction that is equipment which reduces seriousness as much as possible in case of accidents; and active measures, which lead to crash prevention in preventing any accidents from happening. Passive measures could be seatbelt, seatbelt reminder, airbags, and e-call. Active measures are a number of more or less intelligent devices, which help the driver to avoid any accidents: Anti-lock Braking System (ABS), Electronic Stability Control (ESC) and a number of active systems, which aim to assist the driver in keeping appropriate driving behaviour in relation to the surrounding vehicles and road design. They include Following Distance Warning (FDW), Forward Collision Avoidance (FCA), and Lane Departure Warning. Furthermore, there are some variants of Intelligent Cruise Control, which help the driver to set an appropriate speed. These Intelligent Transport Systems (ITS), known as Advanced Driver Assistance Systems (ADAS), include Intelligent Speed Adaptation (ISA), which can be seen as a central solution.

Intelligent Speed Adaptation as a solution

A number of ISA principles have been developed. ISA can be *informative*. It informs the driver about the speed limit for a particular location, often by a display indicating the speed limit. ISA can also be *warning* and give feedback if the speed limit is violated. The feedback can be in the form of flashes from a diode and/or from a display, auditory warnings or in the form of a haptic throttle. The warning ISA is often combined with informative ISA. Furthermore, ISA can be *recording*, which means that driving behaviour is logged and driving data can be used for a number of purposes afterwards or in real time. ISA can also be *incentive*. Incentive ISA is based on recording ISA but is supplemented with a kind of reward or penalty system interrelating driver behaviour and reward/penalty. Furthermore, ISA systems can be *intervening*, which means that they affect driving behaviour physically. In most cases intervention has been based on a dead throttle, which means that the driver cannot depress the throttle even with the intention of speeding. In many ISA trials, the feedback system consists of more than one of these systems.

So far more than 30 ISA trials involving different ISA equipment, different conditions and different groups of drivers have been carried out worldwide. Almost all trials have shown significant effects on driving behaviour. The mean speed decreased in virtually all ISA trials while the effect varied with each trial. Also, the 85 percentile speed decreased even more than did the mean speed. These results are consistent with a generally decreased speed variation, which appeared in most trials as well. Furthermore, the proportion of the distance driven above the speed limit (in some cases plus a few km/h) (PDA) decreased markedly in most trials. Despite a significantly decreased amount of speeding there were virtually no effects on driving time due to ISA. The lasting effect of ISA was, however, in most cases decreasing.

Only one trial allowed measuring the effect on the actual road safety. It was found that with a penetration rate of approximately 10% of the vehicles in a town the result was an uncertain reduction in the number of fatality and injury accidents of 5 to 7% in built-up areas. Estimation of safety effects showed various results depending on several factors and the reduction in the number of fatalities was estimated to be as high as 37 to 42% in some trials if ISA was fully implemented.

ISA has without doubt shown substantial positive effects on the driving behaviour of the participating drivers. The effect on speeding is considerable. However, it was also found that the effect of ISA decreased over time, that in many cases the participating drivers were more positive towards ISA than were the average driver, and that the exposed road users, such as young novice drivers, were underrepresented in most trials. Also, a fundamental hypothesis in many ISA trials seems to be that motorists would like to comply with speed limits but find that it can be difficult in a modern, comfortable car. The assumption is that speeding will be avoided, as drivers who receive such support will no longer violate the speed limits. Most ISA projects have lent support to the hypothesis that speed decreases and most users stated that they found ISA very useful. However, despite the general effectiveness of ISA and users' approval of the systems, only warning ISA, in the form of SpeedAlert, which can rather easily be ignored, has been on the market, and only since late 2008.

Also it was found that young drivers often have a more negative attitude towards ISA as well as towards speed limiting devices in general than have the average driver. It was in most cases found that the drivers who decided to participate in ISA are more risk averse and more positive towards ISA than are the drivers who did not participate. Therefore it seemed reasonable to conclude that more than goodwill is needed for the drivers who need it most to be willing to drive with ISA.

Could it be that even though most participating drivers considered ISA fairly useful, they found it far from satisfactory to drive with? In other words, they found ISA positive but not when it came to their own driving. It seems plausible that an economic incentive linked to speeding behaviour could be the determining factor that might open the market to ISA on a large scale.

Therefore, the set target for the two Danish ISA trials was to develop an efficient incentive-based ISA system on a commercial basis targeting young drivers and commercial drivers. Consequently, the underlying hypothesis guiding essential aspects of the development of the said system was that incentive related to driving behaviour would result in:

- significantly reduced speeding among the participating drivers,
- lasting effect of ISA over time (up to three years), and
- easier recruitment among young drivers.

The two Danish ISA trials

In general, incentive is found to have a significant effect on behaviour. More significant short-term effects than long-term effects are to be expected while lasting effects might be limited or non-existing and highly depend on the nature of the changed behaviour. Also, immediate feedback has a much stronger effect than given later. With that knowledge in mind and the fact that there had been no commercial breakthrough for ISA, the Danish ISA trials were developed. The informative (display showing the speed limit) and warning (female voice message) ISA of the previous Danish ISA trial, *INFATI*, were assessed as highly efficient and selected to be used in combination with incentives to avoid speeding. The two Danish ISA trials were carried out in the period 2004 to 2009. Technically, they were almost identical, however, they involved different types of drivers as test groups as well as different levels of incentive.

Operation mode of the ISA equipment

The trials in question were *Pay As You Speed* (PAYS) and *Intelligent Speed Adaptation Commercial* (ISA C). In PAYS the size of the insurance rate would depend on the driver's amount of speeding. Thus no speeding would result in a 30 per cent reduction on the car insurance rate. The ISA C, a small-scale concurrent ISA trial aimed at commercial drivers, had only a weak incentive in the form of social control plus monthly and final rewards to the drivers with the fewest and smallest speed violations.

In the two ISA trials the feedback system to the driver consisted of a display with small loudspeakers placed in the air-nozzle, a small computer and a GPS antenna. Together these parts were known as the On Board Unit (OBU). Feedback from the OBU was given if the speed exceeded the speed limit by more than 5 km/h. The display would show the actual speed limit, any penalty points received due to speeding during the ongoing trip, and the number of penalty points received during the ongoing test period. Additionally, auditory feedback would be given in the case of speeding. The warning was a female voice telling the speed limit, saying for instance '50' every six seconds. From the third and subsequent warnings penalty points would be added to each warning. The number of penalty points per warning would depend on the seriousness of each speed violation. At the end of a trip, the participant driver could see any received penalty points on a personal webpage. If the participant believed that wrong penalty points had been given, a hotline could be contacted.

In the case of the ISA C, also a personal key ID was handed out to all participants, some of the cars having more than one driver.

Project idea and research design for PAYS

In PAYS, the set target was to have 300 young 18 to 28-year-old car drivers participate over a period of three years. However, recruitment turned out to be very difficult and the trial ended up with 153 participants distributed among all of the age categories but with a majority of young drivers participating in the trial for 12 to 33 months. The equipment was installed during the period April 2006 to January 2008 and was uninstalled until January 2009.

Young drivers were the desired target group because they pay a substantially higher insurance rate on their cars than do other car owners. Also, they are highly overrepresented in accident statistics. Therefore, an ISA trial for this group could be a win-win situation for the young drivers as well as the insurance company and society as a whole. Initially, the drivers in PAYS had a potential bonus equal to 30% of the insurance rate. In the case of speeding, the penalty points 'consumed' the bonus bit by bit until the bonus was used up. The discount was subsequently calculated and paid to the drivers twice a year.

Tabel I: The four different ISA conditions in the PAYS trial.

		Incentive	
		-	+
Information	-	Control group The participant receives neither information nor warnings or penalty points and continues as during the first 1½ months.	Incentive group The display and the voice message are switched off and no information or warnings are given. Speeding gives penalty points, which the participant can then check on the web.
	+	Information group The display and the voice message are connected and information and warnings are given. Speeding gives no penalty points.	Combination group The participant receives information and warnings and gets penalty points if speeding.

The first 1.5 months - the baseline period during which the ISA was not activated - was used to assess each participant's 'normal' driving behaviour. The bonus was independent of the driving behaviour during this period. During the following 4.5 months, the participants were randomly divided into four groups, each driving under different ISA conditions (see Table I).

This segregation made it possible to measure the effect of each part of the ISA system: incentive alone, information and warnings alone, and the two combined. After the period of segregation, all participants drove in the combination mode until the trial was interrupted.

Project idea and research design for ISA C

The ISA C involved 26 commercial cars with 51 drivers for approximately one year. ISA was installed during the period March to June 2007. The first approximately 2 months was a baseline period similar to the one in PAYS. After the activation of ISA, the behaviour of each driver and each car was calculated monthly. The monthly reward was a shopping basket worth about € 40. Moreover, the final top ten drivers received a navigation unit for their private cars. Finally, social control within each company might have worked as an incentive. The monthly and final rewards were meant as an incentive in order to achieve a similar effect to PAYS.

Objective, data and methods

Objective

On the basis of the above-mentioned reflections about how ISA might affect driving behaviour and how incentive works in relation to the two ISA trials, it seems reasonable to ask the following question to increase knowledge about the effect of informing and warning ISA combined with incentive:

> *How are exposed groups of drivers' driving behaviour influenced in the short and medium-term by informative and warning ISA together, incentive ISA, and a combination of these in correlation with incentives of various size and type?*

Short term is here defined as approximately 0 to 2 months after activation of ISA, while medium term is approximately 3 to 6 months after activation of ISA. The main purpose of the ISA trials being to measure the effect on driving behaviour, a study of the change in driving behaviour is carried out. Focus is on exposed road users. Young drivers and commercial drivers are selected because they were the initial target groups in the two ISA trials. Information, warnings, and a combination of the two linked to incentive constitute the ISA treatment of the two Danish ISA trials.

Data

To measure the effect of ISA on driving behaviour data logging was selected. Data logging of driving behaviour called Floating Car Data (FCD) is considerably more accurate than e.g. questionnaire-based answers. Also, the number of participating vehicles does not allow reliable measurements on the basis of general traffic tendencies.

Only results on driving behaviour on roads with 50, 80, 110, and 130 km/h speed limits (subsequently denoted as 50 km roads etc.) are included in this study. The reason for this is that the majority of driving was carried out on these four road types (84 and 91% of the total driving is included in the periods selected in the two trials). Also, results regarding road types with speed limits lower than 50 km/h were omitted because they might be equipped with a speed calming road design, e.g. speed humps, rumple strips, and chicanes. Exposed groups of road users being the area of interest, only drivers aged 18-28 years on entering PAYS were included in these studies. Also, driving data from all vehicles involved in the ISA C trial are included here.

Methods

Three approaches are used to measure the effect of ISA in the two ISA trials: the proportions of the distance driven above the speed limit + 5 km/h (PDA), the Mean Free Flow Speed (MFFS), and the Free Flow Standard Deviation (FFSD). PDA allows any effect on the proportions of the distance driven above the activation level of ISA to be measured. PDA is the most direct way to measure the effect of ISA and so it seems a reasonable approach. Also, it should be noted that the results differ considerably if based on the proportion of the time driven above the speed limit + 5 km/h (PTA) compared to the PDA. PDA ought to be used for yielding more definite and statistically significant results than does the PTA approach. MFFS measures the mean speed of driving deducted all driving slower than a clearly defined speed below the speed limit. FFSD is the standard deviation of driving speed deducted the same data as for MFFS. FFSD shows if the speed variation changes due to ISA. Changed speed variation affects road safety significantly and FFSD was therefore used to measure the effect of ISA.

Results and conclusions

In PAYS, which was aimed at young drivers, the drivers were randomly divided into four groups. Informative and combination feedback was immediately given in case of speeding, while incentive was given after a trip. Control continued under the same conditions as without ISA. In ISA C the drivers drove commercial vehicles. They were immediately given information about any speeding, while incentive was given much later (once a month). Overall concerning PAYS, regarding short-term effects, it was found that the combination of informative, warning and incentive ISA resulted in statistically significant less speeding than did either of them. Moreover, it was found that incentive without informative and warning ISA worked significantly better than informative and warning ISA without incentive. The weak financial incentive and social control regarding ISA C resulted in a change in behaviour, which was somewhat similar to the effect of informative ISA in PAYS. These results hold good, in general, regarding 50 and 80 km roads, which is equivalent to 70% of the data studied. On 110 and especially on 130 km roads the pattern is more confounding. There might be three reasons for that: 1: the distance driven on these road types is short, 2: fewer drivers drove on these two road types, and 3: first results from PAYS and the INFATI trial showed that many drivers found 130 km per hour more than fast enough and therefore only limited effects of ISA could be expected here.

In the medium term the differences between the different ISA treatments became even more substantial. The effect of informative ISA differed markedly but in general decreased over time. Regarding incentive the effect appeared and remained although, in most cases, the effect of combination was significantly bigger than of incentive alone. In most cases the effects regarding ISA C decreased over time, but it should be noted that the smaller and less lasting effect might be due to the weaker incentive but maybe also another type of drivers. On the basis of this study, the connection between the size and type of incentive and the effect on driving behaviour cannot be clarified.

Overall, these results tally very well with what could be expected on the basis of theories and general experience regarding incentive. Financial incentives or something equivalent seems to work better than do incentives, which are less easy to exchange to financial benefits. Also, it was found that incentives which drivers were immediately reminded about had a significantly better effect than had incentives which the drivers were reminded about later. The same connection between incentive and how information about incentives was given was found regarding medium-term effects although the differences were even more significant than regarding short-term ones. However, it should be borne in mind that these results are based on relatively small groups of drivers, and that drivers in most ISA trials are less keen on speeding than is the average driver. Despite this, the overall conclusion is that information and warnings affect driving behaviour somewhat. Immediate incentive affects it more, but the combination of informative and incentive ISA affects driving behaviour the most. This is true of the short as well as the medium term.

Future research should preferably focus on the challenges regarding a large-scale market introduction of ISA aimed at the groups of drivers who are not keen on this type of equipment.

VI Sammenfatning

Der er brug for nye løsninger for at forbedre trafiksikkerheden

Trods markante forbedringer af bilers sikkerhedsudstyr, mere information og et sikrere vejnet, er for dårlig trafiksikkerhed fortsat årsag til et af de største antal dødsfald i verden hvert år. Globalt set omkom mere end 1,27 mio. mennesker i trafikken og 50 mio. kom til skade i 2004. Heldigvis har det vist sig, at forøget velfærd medfører en afkobling mellem økonomisk vækst og stigende trafikrisiko. I den industrialiserede verden har det medført færre ofre i trafikken, selvom trafikomfanget er fortsat med at vokse. Indtil for få år siden faldt antallet af omkomne i trafikken år for år, mens trafikmængden voksede. Denne tendens er blevet erstattet af en mere usikker udvikling med en konstant eller endda stigende risiko i trafikken.

Uhensigtsmæssig hastighed og stor hastighedsvariation er centrale årsager til det store antal omkomne i trafikken. Resultatet er entydigt: Jo højere hastighed, jo højere bliver specielt risikoen for uheld med omkomne. Endvidere medfører den ændrede hastighed, at antallet af alvorlige tilskadekomne påvirkes mere end antallet af lettere tilskadekomne påvirkes. Det er endvidere påvist, at en forøget gennemsnitshastighed medfører en forøget hastighedsvariation, der i særlig grad øger risikoen i trafikken.

Trods indførelse af hastighedsgrænser og det efterfølgende markante fald i antallet af omkomne i trafikken, kører en stor del af bilisterne på vejnettet hurtigere end hastighedsgrænsen. Det gælder også i lande med et højt trafiksikkerhedsniveau. Andelen afviger fra land til land, men det ser ud til, at halvdelen og i nogle tilfælde endda flere kører for hurtigere end tilladt på veje i det åbne land.

Denne meget udbredte kørsel med en hastighed højere end den tilladte kan forklares med, at det at køre for hurtigt belønnes øjeblikkeligt. Rejsetiden reduceres, og de fleste bilister ignorerer risikoen, der er forbundet dermed. Desuden undervurderer de fleste deres hastighed og hvad der er sikkert på den enkelte vej. Følelsen af høj hastighed er også mindsket på grund af mindsket støj og vindmodstand. Det føles sikrere, da en moderne bil føles stabil på vejen, selv med høj hastighed. Denne følelse er antagelig forstærket af f.eks. airbags og ABS, der kan give en falsk tryghed. Derudover nyder mange bilister at køre hurtigt. Endelig kan det siges, at trafikken er en 'dårlig pædagog'. Den enkelte tur føles ekstrem sikker, og den gennemsnitlige chauffør kan køre i adskillige hundrede år, før vedkommende bliver involveret i et politirapporteret uheld med alvorligt tilskadekomne.

Indførelse af hastighedsgrænser har generelt medført en stor reduktion i antallet af dræbte og tilskadekomne i trafikken. Traditionelle værktøjer til at forebygge kørsel med for høj hastighed har været kontrol, information og forbedret indretning af vejnettet. Kontrol er et centralt værktøj. Når bilisten har en risiko for at blive straffet for at overskride hastighedsgrænsen, har det en markant effekt på antallet og alvorligheden af hastighedsovertrædelserne. Effekten af kontrol er dog aftagende over tid såvel på afstand. Endvidere er risikoen for at få en fartbøde meget lille, og den gennemsnitlige chauffør kan køre i mere end 10 år, før vedkommende får en fartbøde. Information er en billig måde at reducere mængden af trafik, der kører for hurtigt. Til dette skal dog siges, at udgangspunktet for overtrædelsen er meget afgørende for effektens størrelse - jo mindre der køres for hurtigt, jo mindre effekt kan der forventes. Trods en generel positiv effekt på hastighedsoverskridelser fra kampagner, skal det bemærkes, at der nu har været gennemført kampagner mod hastighedsoverskridelser i mange år, og det virker ikke plausibelt, at der kan opnås en væsentlig større sikkerhedsmæssig effekt fremover. Designet af vejnettet i de fleste industrialiserede lande forbedres løbende, så sikkerheden højnes. Resultatet er, at antallet af uheld nedbringes, men også at skadesgraden, hvis et uheld sker, mindskes. Generelt er mange lokaliteter, hvor der er flere tilskadekomne end det kunne forventes, de såkaldte sorte pletter, forbedret for at nedbringe antallet af tilskadekomne. Eftersom de farligste sorte pletter efterhånden er ombygget, vil yderligere forbedring af vejdesignet ske på mindre farlige lokaliteter, hvor der kun kan forventes en lille sikkerhedsmæssig effekt. Dermed vil der, trods store investeringer kun kunne forventes en mindre effekt på trafiksikkerheden. Med de ovenstående løsninger, er det samlet set vanskeligt at forbedre trafiksikkerheden i større omfang, og brugen af informations teknologi (IT) i køretøjer åbner op for nye muligheder for at forbedre trafiksikkerheden yderligere. Løsningerne er mangeartede og kan grundlæggende opdeles i to grupper: 'Passive' løsninger, der medfører mindre skadesgrad, når et uheld sker, og 'aktive' løsninger, der forebygger, at uheldet overhovedet sker. Passive løsninger kan være sikkerhedssele, selehusker, airbags og e-call. Aktive løsninger er et antal mere eller mindre intelligente systemer, der hjælper chaufføren med undgå uheld. ABS, ESC og en række andre systemer hjælper chaufføren med at afvikle kørslen på en fornuftig måde. De inkluderer FDW, FCA og advarsler mod kørebaneskift. Endvidere er der nogle varianter af Intelligent Fartpilot, der kan hjælpe chaufføren med at afvikle kørslen med en fornuftig hastighed. Disse Intelligente Transportsystemer er kendt som ADAS inklusiv Intelligent Farttilpasning (ISA), der kan ses som én central løsning på ovenstående problemer.

Intelligent Farttilpasning som en løsning

En række ISA-principper er blevet udviklet. ISA kan være informerende og informerer chaufføren om den øjeblikkelige hastighedsgrænse. Det sker ofte via et display, der viser hastighedsgrænsen. ISA kan også være advarende og give feedback, hvis hastighedsgrænsen overskrides. Feedback kan være som blink fra én diode eller display, auditiv eller via gaspedalen. Advarende ISA har i mange tilfælde været kombineret med informerende ISA. ISA kan endvidere være registrerende, så kørselsadfærden logges og anvendes til forskellige formål, enten efterfølgende eller i real tid. Derudover kan ISA være incitamentbaseret. Dette er normalt baseret på registrerende ISA og giver mulighed for at belønne/straffe chaufføren, alt efter hvordan hastighedsgrænserne overholdes. Endelig kan ISA være indgribende, så chaufføren forhindres i at overskride hastighedsgrænsen. Oftest styres det ved, at chaufføren ikke kan give gas, hvis hastighedsgrænsen er overskredet. I mange ISA forsøg har flere af disse systemer til feedback været kombineret.

Indtil videre har der været mere end 30 forsøg med ISA rundt omkring i verden. Forsøgene har været med forskellige systemer, forskellige betingelser og forskellige deltagergrupper. Næsten alle forsøg har vist en markant effekt på kørselsadfærden. Gennemsnitshastigheden blev reduceret i næsten alle forsøg, men reduktionens størrelse afveg meget imellem de forskellige forsøg. 85 % fraktilen blev reduceret endnu mere end gennemsnitshastigheden. Disse resultater hænger godt sammen med den reducerede hastighedsvariation, der ligeledes blev fundet i mange forsøg. Endvidere faldt andelen af den kørte distance over hastighedsgrænsen (i nogle tilfælde plus nogle få km/t) markant i de fleste forsøg. Trods den store reduktion i kørslen med for høj hastighed var der i realiteten ingen effekt på transporttiden. Hvor det blev undersøgt, var effekten i de fleste tilfælde aftagende over tid.

Kun ét forsøg har været af en størrelse, så effekten fra ISA kunne måles på den faktiske trafiksikkerhed. Cirka 10 % af køretøjerne i en by blev udstyret med advarende ISA. Det resulterede i et usikkert resultat på 5-7 % færre uheld med dræbte eller tilskadekomne i byområder. Estimater på sikkerhedseffekten fra ISA viser varierende resultater afhængig af en række faktorer, men det estimeres, at antallet af dræbte i trafikken kan reduceres med op til 37-42 %, hvis ISA var i brug i alle køretøjer.

ISA har resulteret i en utvetydig positiv effekt på kørselsadfærden blandt de deltagende chauffører. Effekten på hastighedsovertrædelser er markant. Til det skal det dog bemærkes, at effekten af ISA aftager over tid, og at de fleste deltagende chauffører var mere positive over for ISA end deres modparter, der ikke deltog i forsøgene, samt at særligt udsatte grupper af bilister, som for eksempel unge bilister var underrepræsenterede i de fleste forsøg. Endvidere har en grundlæggende hypotese i mange ISA-forsøg været, at bilisterne gerne vil overholde hastighedsgrænsen, men finder det vanskeligt i en moderne komfortabel bil. Antagelsen er, at hastighedsoverskridelser vil blive undgået, og at de chauffører, der får ISA-feedback, ikke længere vil overskride hastighedsgrænsen. Denne hypotese støttes af resultaterne i de fleste ISA-forsøg, hvor hastighedsoverskridelserne blev langt færre, og hvor deltagerne fandt ISA meget brugbart. Til det bør det noteres, at trods alle de positive effekter og holdninger i forbindelse med ISA, er det kun advarende ISA, og kun med et system, der nemt kan ignoreres af chaufføren, der er kommet på markedet, og det kun i de seneste år.

Forskning viser endvidere, at unge mennesker ofte er mere negative i forhold til ISA såvel som i forhold til hastighedsbegrænsende systemer, end den gennemsnitlige bilist er. I de fleste tilfælde blev det fastlagt, at de deltagende bilister i ISA-forsøg var mindre risikosøgende og mere positive over for ISA end den gennemsnitlige bilist var. Det virker derfor plausibelt, at der skal mere end goodwill til, for at få de mest udsatte grupper af bilister til at acceptere at køre med ISA.

Kunne det være tilfældet, at selvom de fleste deltagende chaufførere fandt ISA ganske brugbart, fandt det mindre tilfredsstillende at køre med? Med andre ord fandt de ISA meget brugbart - blot ikke, når de selv skulle køre med det. På den baggrund virker det plausibelt, at et økonomisk incitament relateret til at undgå hastighedsoverskridelser, kunne være den afgørende faktor til at få ISA implementeret på markedsvilkår i større skala.

Derfor var målene med to danske ISA-forsøg at udvikle et effektivt incitamentbaseret ISA-system på markedslignende vilkår rettet mod grupperne af unge bilister og chauffører i firmabiler. De bagvedliggende hypoteser, der styrede centrale dele af udviklingen af ISA-systemet, var at et incitament relateret til kørselsadfærden ville resultere i:

- Markant reduktion i antallet af hastighedsovertrædelser.
- Blivende effekt fra ISA (i op til tre år).
- En nemmere rekruttering blandt unge bilister.

De to danske ISA-forsøg

Forskning viser generelt, at incitament påvirker adfærd markant. Der kan forventes større korttids- end langtidseffekt, mens blivende effekter er begrænsede og afhænger af hvilken type adfærd, der ønskes ændret. Endvidere kan der forventes en større effekt, hvis feedback modtages straks fremfor med forsinkelse. Den viden, samt det faktum at ISA ikke var slået kommercielt igennem, var baggrunden for udviklingen af de danske ISA forsøg. Informativ ISA (display, der viser hastighedsgrænsen) og advarende ISA (stemmebesked) fra det gamle danske ISA-projekt, INFATI, blev vurderet som meget effektivt, og blev anvendt sammen med incitamenter for at undgå hastighedsoverskridelser. De to danske ISA-forsøg blev gennemført i perioden 2004-2009. Teknisk var ISA-udstyret stort set ens i de to forsøg, men det var forskellige målgrupper og typer af incitament, der var involveret.

ISA-udstyrets virkemåde

De to forsøg var *Spar På Farten* (SPF) og *Spar på Farten - Tab ikke kunder i svinget* (SPF-K). I SPF afhang størrelsen på deltagernes bilforsikring af, hvor meget de kørte for hurtigt. I det mindre sideløbende SPF K rettet mod erhvervschaufførere var incitamentet svagere og bestod af social kontrol samt én månedlig samt et antal endelig præmier til chaufførerne, der havde kørt mindst for hurtigt.

ISA-systemets feedback i de to ISA-forsøg bestod af et display med små højtalere placeret i ventilationsdyssen til højre for rattet, en lille computer samt en GPS-antenne.

Tilsammen blev disse dele benævnt On Board Unit (OBU). Feedback fra OBUen blev givet, hvis hastighedsgrænsen blev overskredet med mere end 5 km/t. Displayet viste den aktuelle hastighedsgrænse, eventuelle strafpoint modtaget for at have kørt for hurtigt under den igangværende tur, samt det samlede antal strafpoint modtaget i indeværende testperiode. Tillige blev der givet auditiv feedback til chaufføren, hvis der kørtes for hurtigt. Advarslen var en kvindestemme, der nævnte hastighedsgrænsen, f.eks. ’50’ hvert sjette sekund. Fra og med den tredje advarsel blev hver advarsel fulgt af strafpoint. Antallet af strafpoint pr. advarsel afhang af, hvor alvorlig overtrædelsen var. Efter afslutningen af en tur havde bilisten adgang til at se eventuelle modtagne strafpoint på en personlig hjemmeside. Hvis bilisten mente, at et eller flere strafpoint var forkerte, kunne en hotline kontaktes.

I SPF-K havde de deltagende chauffører tillige en personlig nøgle-ID, der blev delt ud til alle deltagende chauffører, fordi enkelte biler havde mere end én chauffør og den enkelte chauffør derfor ikke skulle lægges til last for, hvordan andre chauffører på køretøjet opførte sig.

Projektidé og forskningsdesign for SPF

Det var målet at have 300 18-28-årige bilister som deltagere i SPF. Det viste sig dog, at rekrutteringen var endog meget vanskelig. Det endte derfor med, at cirka 153 deltagere fordelt på alle aldersgrupper, men med en overvægt af unge, deltog i forsøget i imellem 12 og 33 måneder. ISA-udstyret blev installeret i perioden april 2006 til januar 2008 og de sidste OBUer blev afinstalleret i januar 2009.

Unge bilister var målgruppen, fordi de betaler en meget højere forsikringspræmie på deres biler end andre bilejere. Desuden er de meget stærkt overrepræsenterede i uheldsstatistikkerne. Af den grund kunne kørsel med ISA blandt denne gruppe være en win-win situation for både de unge, forsikringsselskabet og for samfundet som helhed. Som udgangspunkt havde deltagerne en bonus svarende til 30 % af deres bilforsikringspræmie. Hvis de kørte for hurtigt blev bonussen ’spist op’ bid for bid, indtil den var brugt. Den eventuelle bonus blev efterfølgende beregnet og udbetalt til bilisten to gange om året.

De første 1,5 måneder, kaldet baselineperioden, hvor ISA var inaktivt, blev brugt til at dokumentere deltagerens ’normale’ kørselsadfærd. Bonussen i den periode var uafhængig af deltagerens kørselsadfærd i perioden. I de følgende 4,5 måneder var deltagerne fordelt tilfældigt i fire grupper, der kørte under forskellige ISA-forhold (se Tabel II).

Denne opdeling gør det muligt at måle effekten af hver del af ISA-systemet: Incitament alene, information sammen med advarsler alene samt de to i kombination. Efter denne periode med opdeling kørte samtlige deltagere under kombinationsforholdene indtil forsøget blev afbrudt.

Tabel II. De fire forskellige ISA-forhold, som deltagerne kørte under i SPF.

		Incitament	
		-	+
Information	-	Kontrolgruppe Display og højtaler er slået fra og der gives hverken information eller advarsler. Deltagernes får forsikringsrabat uanset kørselsadfærden.	Incitamentsgruppe Display og højttaler er slået fra og der gives hverken information om hastighedsgrænsen eller advarsel når den overskrides. Det koster strafpoint, hvis der køres for hurtigt, og deltageren kan se disse på Nettet.
	+	Informationsgruppe Display og højttaler er slået til og der gives både information og advarsler. Deltagernes får forsikringsrabat uafhængigt af kørselsadfærden.	Kombinationsgruppe Display og højttaler er slået til og der gives både information og advarsler. Deltagernes forsikringsrabat afhænger af kørselsadfærden.

Forskningsdesign for SPF-K

I SPF-K projektet medvirkede 26 firmabiler og 51 chauffører i cirka ét år. ISA blev installeret i bilerne i perioden marts til juni 2007. De første cirka 2 måneder var en baselineperiode som den i SPF. Efter aktiveringen af ISA, blev kørselsadfærden i hver bil og for hver deltagende chauffør beregnet månedlig. Den månedlige belønning for pæn kørsel var en indkøbskurv til en værdi af ca. 300 DKK. Desuden fik de ti chauffører med meget få strafpoint i hele forsøgsperioden et navigationsanlæg til deres private bil. Endelig var der også et eller andet omfang af social kontrol internt i de deltagende virksomheder. De månedlige og afsluttende belønninger sammen med den sociale kontakt var tænkt som incitamenter med henblik på at skabe en effekt i retning af den, der blev opnået i SPF.

Problemformulering, data og metoder

Problemformulering

På baggrund af ovenstående overvejelser omkring hvordan ISA formodes at påvirke kørselsadfærden og hvordan incitamenter kan forventes at virke, stilles følgende spørgsmål, for at øge viden om effekten af informerende og advarende ISA, når det kombineres med incitamenter:

> *Hvordan påvirkes udsatte bilistgruppers kørselsadfærd på kort og mellemlang sigt af informerende ISA, advarende ISA og kombinationen af disse, når dette bygges sammen med incitamenter af forskellig størrelse og type.*

Kort sigt er her defineret som cirka 0 til 2 måneder efter aktivering af ISA. Mellemlang sigt er 3 til 6 måneder efter aktivering af ISA. Hovedformålet med ISA-forsøgene var at måle effekten på kørselsadfærden, hvorfor en undersøgelse af ændringerne i kørselsadfærden er gennemført. Fokus har været på særligt udsatte trafikantgrupper, og unge bilister og erhvervschauffører er valgt, fordi de var de oprindelige målgrupper i de to ISA-forsøg. Information, advarsler og kombinationen af disse i sammenhæng med incitamenter er hovedemnerne for de to danske ISA-forsøg.

Data

For at måle effekten på kørselsadfærden fra ISA blev logninger af kørselsdata anvendt. Logning af kørselsadfærd kaldet Floating Car Data (FCD) er meget mere præcise end de svar, der kan opnås fra f.eks. spørgeskemaundersøgelser. Endvidere har antallet af deltagende køretøjer været af en størrelse, der ikke gjorde det muligt at måle effekten fra ISA på forsvarlig vis på de generelle trafikdata.

Kun resultater fra kørsel på veje med 50, 80, 110, and 130 km/t hastighedsgrænse (efterfølgende benævnt 50 km vej etc.) er medtaget i dette studie. Årsagen hertil er, at hovedparten af den kørte distance i de to forsøg, er foretaget på disse vejtyper (84 og 91 % af den totale kørsel i de perioder af forsøgene, der er inkluderede i dette studie). Endvidere må effekten fra ISA betragtes som usikker på vejtyper med en hastighedsgrænse lavere end 50 km/t, fordi disse ofte er udstyrede med hastighedsdæmpende foranstaltninger. Data medtaget i dette studie er fra bilister yngre end 29 år på installationstidspunktet i SPF samt alle deltagende biler i SPF-K.

Metoder

Tre tilgange er anvendt til at måle effekten af ISA i de to ISA-forsøg: Andelen af den kørte distance, der blev kørt med en hastighed højere end hastighedsgrænsen + 5km/t (PDA), den gennemsnitlige free flow hastighed (MFFS) og Standardafvigelsen af Free Flow hastigheden (FFSD). PDA muliggør, at enhver påvirkning af andelen af den kørte distance, der blev kørt hurtigere end aktiveringsgrænsen for ISA-udstyret måles direkte. I den forbindelse skal det noteres, at resultater af denne type afviger markant afhængig af, om der måles på tidsforbrug eller på den kørte distance. PDA muliggør mere markante resultater end den tidsbaserede tilgang giver mulighed for (PTA). MFFS måler gennemsnitshastigheden af den kørsel, der er foretaget med en højere hastighed end en klart defineret grænse, der ligger noget lavere end hastighedsgrænsen. FFSD er standardafvigelsen af kørslen fratrukket de samme lave hastigheder som for MFFS. FFSD viser, om hastighedsvariationen ændredes som følge af ISA. Ændret hastighedsvariation påvirker trafiksikkerheden markant, og FFSD er derfor anvendt til at måle effekten af ISA.

Resultater og konklusion

I SPF, der var rettet mod unge bilister, var deltagerne fordelt tilfældigt i fire grupper. Information og kombination fik feedback øjeblikkeligt, hvis aktiveringsniveauet for ISA-systemet blev overskredet, mens incitament først resulterede i feedback, efter en tur var afsluttet. Kontrol fortsatte som inden ISA blev aktiveret. I SPF-K var deltagerne erhvervschauffører. De fik øjeblikkelig besked, hvis der blev kørt for hurtigt, men incitamentet for at undgå at køre for hurtigt blev givet langt senere (én gang pr. måned). Omkring SPF var den overordnede effekt på kort sigt, at kombinationen af information sammen med advarsler og incitament medførte et statistisk signifikant lavere PDA end de gjorde hver for sig. Det kunne endvidere konkluderes, at incitament uden information virkede bedre end information uden incitament. Det relativt lille incitament samt den sociale kontrol i SPF-K resulterede i en ændring i kørselsadfærden, der var sammenlignelig med, hvad der kunne opnås fra information i SPF. Disse resultater er konsistente for 50 og 80 km veje, som dækker ca. 70 % af den kørsel, der indgår i dette studie. På 110 og specielt på 130 km veje er effekterne mere uklare. Der kan identificeres tre mulige årsager hertil: 1: Den kørte distance på disse vejtyper er kort. 2: Færre af de deltagende chauffører kørte på disse vejtyper. 3: De første resultater fra SPF og fra INFATI viste, at mange chauffører mente, at 130 km/t er mere end hurtigt nok, hvorfor der kun kan forventes mindre effekter på disse vejtyper.

På mellemlangt sigt var forskellen mellem kørslen under de forskellige ISA-forhold endnu mere markant. Effekten af information var meget svingende, men reduceredes generelt over tid. Incitament resulterede i stort set samme effekt på kørselsadfærden, mens kombination resulterede i en effekt, der var statistisk signifikant bedre end for incitament. Med hensyn til SPF-K aftog effekten i de fleste tilfælde over tid. I den forbindelse bør det noteres, at den reducerede effekt som følge af ISA kan skyldes et mindre incitament for at undgå at køre for hurtigt, men også at det er en anden type chauffører. På baggrund af dette studie kan det ikke afklares, om der er en sammenhæng mellem incitamentets størrelse og effekten af dette.

Generelt passer disse resultater godt med, hvad der kunne forventes baseret på erfaringer og teorier om incitamenter. Finansielle incitamenter, eller lignende, der kan veksles til penge, virker tilsyneladende bedre end incitamenter, der ikke kan veksles til penge. Det blev endvidere fundet, at incitamenter, er blev givet med det samme havde større effekt end dem, der blev givet senere. Denne effekt var endnu mere markant på mellemlang sigt, end den var på kort sigt. Hovedkonklusionen er, at informerende ISA påvirker kørselsadfærden i nogen grad, incitament givet øjeblikkeligt virker bedre, mens kombinationen af incitament og information påvirker kørselsadfærden mest. Disse resultater er gældende for såvel kort sigt, som mellemlang sigt.

Fremtidig forskning bør fokusere på, hvordan ISA kan udbredes, så unge og andre særligt udsatte grupper, der normalt undgår denne type udstyr, kan overbevises om det brugbare i forsøget.

1 Background

1.1 Road safety as a continuing problem

Road safety is one of the biggest issues regarding loss of years of life. In 2004, it was estimated that more than 1.27 million people globally died in road accidents while the number of injured was estimated as high as 50 million. Moreover, it was estimated that these numbers will increase to 2.4 million fatalities over the next 20 years unless an extraordinary effort is carried out. It is even expected to increase as much as 80% in low- and middle-income countries (World Health Organization 2009). Additionally, it is an area which attracts much smaller funding for research than do other big causes of loss of years of life (World Health Organization 2004, World Health Organization 2009).

There is no direct connection between the number of cars and the number of fatalities. With increased welfare more cars will drive on the road network, which at first results in more fatalities. However, this connection disappears later on due to more regulation of driving behaviour, increasing quality demands for cars, improved road network quality and a more forgiving design (EuroRap 2009). Generally speaking these improvements result in fewer road fatalities and fewer traffic injury victims even though the number of vehicles continues to grow. This is a worldwide trend and the principles of this development can be illustrated by a Kuznets curve as shown in Figure 1.1 (Moniruzzaman, Andersson 2006).

Most industrialised countries are placed somewhere on the decreasing part of the Kuznetz Curve and had until a few years ago experienced a more or less stable trend towards fewer fatalities in road accidents. However, in the last decade that decrease has diminished or has even turned into an increase in the number of fatalities in some countries, e.g. Australia, Canada, Denmark, Greece, Ireland, and the US (Australian Transport Safety Bureau 2007, Hemdorff 2008). To model the newest development in road safety in these countries a modified version of the Kuznetz curve is suggested as useful. See Figure 1.2.

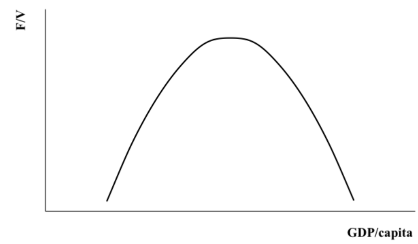


Figure 1.1. A Kuznetz curve showing the link between Gross Domestic Product per capita (GDP/capita), the number of fatalities per vehicle (F/V), and the fatality rate for road accidents.

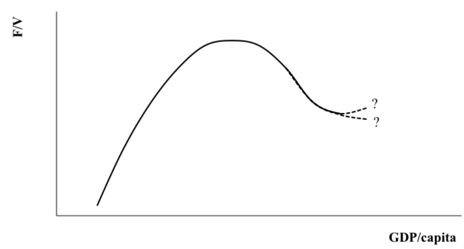


Figure 1.2. A modified Kuznetz curve, which is suggested to image, the change in road safety related to the GDP/capita so far (own modifications).

The reasons for this fading reduction in the number of road fatalities are probably multifaceted, and no clear solutions are available. Despite this challenge, many industrialised countries have defined a clear set of goals concerning road safety improvements. For example the European Commission in 2010 set itself the target of reducing the European road fatalities by 50% by 2020 compared to 2010. This target was built on the former Road Safety Action Plan, which likewise worked towards a halving of the number of road fatalities. However, in 2009 only a reduction of 36% had been reached and 34,500 road fatalities were still reported each year (European Commission 2010). Also, the Danish road authorities work toward a 40% reduction in the number of fatalities and severely injured persons by 2012 compared to 1998. Until 2006 a promising development pointed towards an even better result. An even more ambitious target was therefore set in 2007: a 40% reduction in the numbers of fatalities compared to the result in 2005. Nevertheless, in 2007 and 2008 the number of fatalities increased substantially again. And the significant decrease that appeared in 2009 and 2010 (Danish Road Directorate 2010, Statistics Denmark 2010) might probably not be sufficient to reach the set target. Similar challenges can be found in other countries, and the key issue is to re-establish the Kuznetz curve regarding road safety.

1.2 Speeding and speed variation are central causes

It is well documented that higher speeds on a road network lead to a higher number of road fatalities, as represented by the Power Model developed by Göran Nilsson (2004). Changed speed limits in different kinds of road systems and changed mean speeds have been associated with a changed accident rate on these road systems. Based on the changes in speeds and accident rates, the Power Model has been formulated as below.

$$\frac{\text{Accidents after}}{\text{Accidents before}} = \left(\frac{\text{Speed after}}{\text{Speed before}}\right)^{X}$$

The power is here stated as X and can be replaced with 2, 3, or 4 in cases of injury accidents, severe injury accidents, or fatal accidents, respectively. The results are clear: the higher the speed, the higher the number of especially fatalities. Moreover, the change in speed affects the number of serious accidents more than the number of minor ones (Nilsson 2004).

Also Elvik et al. (2004) carried out a large-scale study. They agreed in general with the model and found that the most adequate value of power in relation to fatalities was 4.5.

The Power Model is a well-reputed tool for estimating the effect of speed changes on a road network. It shows that a higher speed in traffic in general is a major challenge regarding road safety.

In addition to that, the connection between mean speed and accident risk was recently documented in a Danish study regarding the increased speed limits from 110 km/h to 130 km/h on selected motorways, implemented in May 2004. The result was an overall increase in the numbers of injury accidents of 14% on the roads with increased speed limits, while the general tendency on the Danish road network was a decrease of 15%. On the 130 km/h roads, the mean speed increased by about 1% (Danish Road Directorate 2008), which underpins the connection between speed and accident risk as shown by the Power Model. It even indicated higher exponents than suggested in the Power Model.

Finally, it is found that higher mean speed results in increased speed variation and that higher speed variation results in higher accident risk (Salusjärvi 1981, Finch et al. 1994). Hence, though speed variation can be assumed to be included in the Power Model, because mean speed affects speed variation, it should be borne in mind that a change in driving behaviour affects the road safety level to a higher degree than expected from a change in mean driving speed.

1.3 Speed limits and speed limit violation

In the sixties and early seventies the number of fatalities due to accidents on the road networks increased markedly in many industrialised countries (World Health Organization 2009). Speed limits were in general introduced for all road types in most industrialized countries in 1970-1975 (Elvik et al. 2009). Speed limits affect the number of fatalities significantly in most cases and most developed countries have speed limits implemented today (Elvik, Christensen & Amundsen 2004, Elvik et al. 2009). An example illustrates the effect of introducing speed limits: in the United Kingdom no speed limits were set outside built-up areas until 1965 when a 70 mph speed limit was introduced (Safer Motorings 2011). Despite a significant increase in the traffic volume over the next years, the number of fatalities did not reach the previous level of the years around the introduction of speed limits (Department for Transport 2002). Also, in Switzerland there was no speed limit outside built-up areas before 1973 (Swiss Federal Roads Office 2009). In Switzerland the introduction of general speed limits also resulted in a reduced number of fatalities (Swiss Federal Statistical Office 2010). In Denmark the general speed limit was introduced in 1974 (Burchardt, Schønberg 2006). The safety effect due to the introduction of speed limits in the two latter countries is unclear because the Oil Crisis reduced the traffic volume in those years. However, when the traffic volume picked up again after the Oil Crisis, the change in the number of fatalities was disconnected from the change in traffic volume - exactly as it was found regarding the effect in the United Kingdom. The effect of the introduction of speed limits on road fatalities is indicated in Figure 1.3.

Despite the introduction of speed limits and the subsequently reduced number of fatalities, speed limit violating driving behaviour is still widespread, also in countries with a high road safety level as e.g. Sweden and Norway. In Sweden in 2004, it was found that only 43% of the distance driven on the national roads was driven without speed limit violations. And also that the average speed during speed violations exceeded the speed limit by 10 km/h. These results largely agree with the results in most European countries (Vägverket 2008). A recent study, which, among other things, compares the proportion of speeding on roads in Scandinavia, found that

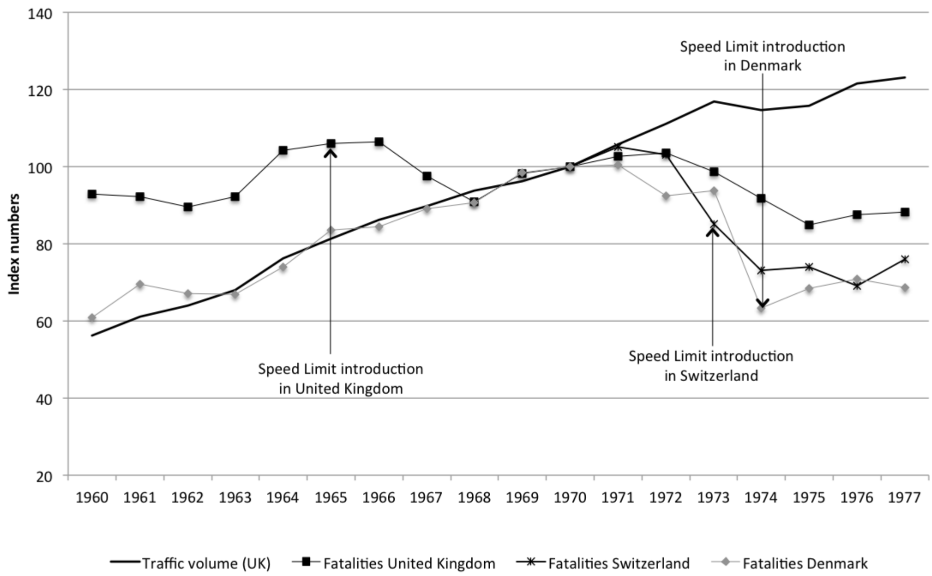


Figure 1.3. Development in number of fatalities in the United Kingdom, Switzerland, and Denmark, and the traffic volume in the United Kingdom[1]. Index numbers, 1970=100. Data regarding Switzerland were only found available from 1970 and onwards.

the majority of drivers exceeded the speed limits. On roads outside built-up areas the proportion was 45, 50, 55, and 71% for Norway, Sweden, Finland, and Denmark, respectively, while also significant proportions of drivers were found to be speeding on other road types. (Eksler, Popolizio & Allsop 2009)

The substantial amount of speeding can be explained by the fact that the reward of speeding is immediate: experienced reduced transportation time. Hence it is easy for drivers to ignore or repress any speeding-related risk. Also, most people underestimate their speed and what the road condition might allow. This phenomenon is found in several studies on speed choice as well as on road safety (Várhelyi 1996). The result is a higher speed than if drivers were fully aware of the risks. Furthermore, in a modern car the feeling of speed is reduced due to e.g. less engine noise and wind resistance. In addition, there is a strong feeling of security. Even at high speeds, a modern car feels stable and calm on the road. And this feeling is supported by equipment such as Anti-lock Braking System (ABS) and airbags, which might give the driver a false feeling of safety (Farmer et al. 1997). In addition, many drivers have a feeling of joy when driving at high speeds - this applies especially to young male drivers, who might also find speed limits unnecessary (Harms et al. 2008, Mogensen 2002).

[1] It seems reasonable that the development in traffic volume has been almost similar in the three countries.

Moreover, one might say that traffic is a bad educator. That is due to the fact that e.g. an average Danish driver would have to drive for almost 800 years before he/she would be involved in a police-reported accident causing severe injuries or fatalities in the car (Statistics Denmark 2010). Also Nilsson (2004) showed that an average Swedish car could drive in approximately 205 years before it would be involved in a police reported accident with injured.

Finally, an Australian study tested the danger of drink driving and of speeding. The suggestion was that a 10 km/h increase in speed increased the risk as much as a 0.05% level of alcohol (BAC) in the blood. However, there are absolutely no similarities between the penalty for speeding and drink driving although they involve the same level of risk. In both Australia and Sweden drink driving is punished more than 10 times more than speeding, which is just as dangerous (Kloeden et al. 1997). It is reasonable to assume that this is the case in most industrialised countries.

1.4 Traditional speed limiting solutions

Despite the fact that a large proportion of road users in most countries violate the speed limits on a large scale, the introduction of speed limits has still resulted in a considerable reduction in road fatalities. To reach the best possible level of road safety a multi-facetted approach is necessary and all available solutions should be used (Haddon 1970). Traditional solutions to prevent speed violation comprise enforcement, information, and enhanced road design.

Enforcement is a central solution. Involving the risk of drivers getting caught in case of speeding it has considerable effect on the number of speed limit violations. However, Várhelyi (1996) found in a number of references that the effect of enforcement is considerable but it is transient in space as well as in time. Also, the risk of getting penalised for violating the speed limits is low. In Denmark in 2008, the total traffic on the road network was 48.9 billion km, an average of 17,300 km per vehicle per year (Statistics Denmark 2010). The same year the Police pressed charges against 202,673 road users for speed limit violations (Politiet 2010). Thus the average driver can drive for approximately 14 years before he/she is likely to get a fine for violating the speed limit.

Information is an inexpensive way to reduce speed violation. However, the baseline level upon which a campaign has to build influences the potential level of change considerably. The less speed violation in baseline, the less effect can be expected (Elliott 1993). A markedly higher impact can be reached if the campaign is associated with enforcement and vice versa (Elliott 1993). In line with that, it was found that campaigns not followed by other initiatives have virtually no effect (Vaa et al. 2004). The period length of a campaign has significant effect as well. A length of more than 200 days results in markedly decreased effect. Vaa et al. (2004) found that the overall reduction in the number of road accidents due to campaigns was approximately 9% during the campaign period and 15% afterwards. While Vaa et al. (2004) found results regarding all traffic-safety-related campaigns, Elliott (1993) found a generally positive effect of campaigns against speed violations also. Despite these positive effects of campaigns for road safety, it should be noted that information campaigns against speed violations have been carried out for many years, probably with significant effect. However, it is not obvious that further significant effects can be achieved concerning speed violations. Also, the effect of campaigns might have been overestimated due to selection bias as evaluations of less efficient campaigns are probably not published as frequently (Elliott 1993, Vaa et al. 2004). Hence, the definitely positive effects of campaigns on road safety should maybe be seen as less significant than the results seem to suggest. It could be that campaigns are necessary in combination with other measures to keep an existing level of road safety, but it is questionable whether an even higher traffic safety level can be achieved that way.

Road design in most industrialised countries is under continuous development towards a safer structure with a view to minimising the number of accidents, and towards a more forgiving structure of the road design in the event of crashes (European Commission 2010). In Denmark, roundabouts thus replace intersections, four way intersections are replaced by staggered three way intersections, vulnerable road users are separated from motorised vehicles, to mention some of the more widely used solutions (Færdselssikkerhedskommissionen 2007). In general, the locations where the number of accidents is higher than expected - the so-called black spots - are enhanced to eliminate the over-representation of accidents there. It seems to have worked well (Elvik et al. 2009). However, as the most problematic black spots have been enhanced with a considerable safety benefit, focus has consequently been turned towards the remaining (and less dangerous) spots (SWOV 2007). In the latter spots, only small safety benefits can be expected. The black spots being in general eliminated, it is hard to gain further safety benefits by improving the road design unless at very high costs (SWOV 2007). Traffic-calming measures have shown significant safety effects. In a meta-analysis, area-wide urban traffic calming schemes were found to reduce the number of injury accidents significantly (Elvik 2001), and traffic calming measures on thoroughfares in minor towns and villages in Denmark have shown significant effects on road safety (Wellis et al. 2004), just to mention a few examples. As for black spot treatment most of the less safe areas have been enhanced, and it seems reasonable to assume that further road safety improvement is difficult to reach without very high costs.

1.5 Additional solutions based on information technology

Equipment in vehicles to improve road safety can be seen as supplemental approaches concurrent to traditional solutions. They are multifarious and can basically be divided into two groups: *passive* measures which lead to loss reduction that is equipment which reduces seriousness as much as possible in case of accidents; and *active* measures which lead to crash prevention in preventing any accidents from happening. It would take us too far afield to mention all the types of equipment, which are available for a modern vehicle, but the following are a few of the most significant:

Passive measures could be seatbelt, seatbelt reminder, airbags, and e-call. Seatbelt use is mandatory in most countries, and all new cars and the majority of older cars are equipped with seatbelts. Wearing seatbelts significantly reduces the risk in case of an accident (Elvik et al. 2009). A seatbelt reminder warns the drivers if the seatbelt is not worn while driving, and it is found to have a statistically significant effect on usage (Regan et al. 2006a). Also, most new cars are equipped with airbags. It is one or several inflatable balloons, which will inflate rapidly if the vehicle decelerates more than a certain level. Hence they help to protect the passengers from hard interior objects such as the steering wheel, and they reduce accident damages significantly (Elvik et al. 2009). Finally, there is e-Call, which will consist of a Europe-wide, harmonised in-vehicle emergency call. In the event of a crash, the e-Call system in the vehicle involved transmits an emergency call directly to the nearest emergency dispatch centre. It can also be triggered manually. It has not been implemented so far but is planned to cover all Europe within a few years (European Parliament 2006). It is estimated to reduce the number of fatalities in the EU by 6-7% while the safety effect in densely populated countries such as Denmark might be minor (Hellung Larsen 2007).

Active measures are a number of devices, which help the driver to avoid any accidents. Anti-lock Braking System (ABS) is one of the most widespread active measures. It is a system that prevents the driver of a vehicle from blocking the wheels during braking manoeuvres. It was scheduled to reduce the number of severe accidents, especially under bad weather conditions because it reduces braking distance significantly. Research results from the childhood of the ABS indicated that even though ABS can achieve a minor reduction in the number of injury accidents, it still results in an increase in the number of fatal accidents. The increase was mainly due to more single vehicle accidents and a higher frequency of collision with fixed objects. It is likely that the problem with ABS was that it led to risk-compensating driving behaviour such as higher speeds and more aggressive driving (Elvik et al. 2009)[2]. Also Farmer (1997 and 2001) found that the safety effect of ABS is questionable. However, it is plausible that improved ABS technology and the fact that ABS is now fairly common in most vehicles in Western Europe has resulted in safety benefits from this measure which more than neutralise any risk-compensating driving behaviour.

Another active measure, Electronic Stability Control (ESC) has a substantial positive effect on road safety. In a study, Ferguson (2007) found that the number of some types of fatal single accidents decreased by 30 to 90% when driving with ESC. Overall, it is expected to reduce the total number

[2] The 2009-version of the Handbook of Road Safety Measures includes only studies of the safety effects from ABS, which are older than 2001.

of fatalities by 15 to 20% (eSafety Support 2010). Due to the significant safety effect it is now widely implemented in new cars and will probably be almost 100% implemented in most industrialised countries within a few years.

There are also a number of active systems, which aim to assist the driver in keeping appropriate driving behaviour in relation to the surrounding vehicles and road design (Bishop 2005). Following Distance Warning (FDW) and Forward Collision Avoidance (FCA) are systems, which either warn the driver or intervene if the headway is too short (Bishop 2005). FDW results in significantly more appropriate distances and fewer variations in the distance to the headway vehicle (Regan et al. 2006a). Lane Departure Warning warns the driver if the driver mistakenly begins to stray the vehicle out of the lane/road. It is supposed to have a significant safety effect, because it reduces the likelihood of head-on accidents and single accidents (Bishop 2005). Furthermore, there are some variants of Intelligent Cruise Control, which help the driver to set an appropriate speed. However, if it works voluntarily, it has been found that many drivers increase the set speed above the speed limit (Jamson et al. 2006). On the other hand, if it works autonomously, resistance on the part of road users might be significant, which will be discussed later. These Intelligent Transport Systems (ITS), known as Advanced Driver Assistance Systems (ADAS), include Intelligent Speed Adaptation (ISA) (Carsten, Tate 2005) and will be elaborated on later.

1.6 Summary

Poor road safety results in more than 1.2 million fatalities and 50 million injured each year, worldwide. Hence it is a topic, which needs continuous attention to reduce these numbers substantially. Fortunately, there is no direct relation between car occupancy rate and the risk of fatalities. Until a few years ago, increased welfare combined with more regulations, better car quality, and more safe and forgiving road design, resulted in substantially better road safety, even though car use and hence exposure continued to increase. However, this positive development has become more uncertain or non-existent in many industrialised countries in the last few years.

A central factor responsible for a significant proportion of all injury and fatal accidents is inappropriate speed choices. It is well-established that reduced speed on the roads results in reduced risk of fatalities. Nevertheless, a significant proportion of the distance driven in most countries is carried out above the set speed limits. Traditional solutions to prevent speeding such as campaigns, police enforcement, and enhanced road design have contributed to better road safety, but it seems reasonable to see further solutions based on ITS, and ISA in particular, as a central supplementary solution towards better road safety through reduced speeding.

2 Intelligent Speed Adaptation as a solution

2.1 Initiating approach

ISA is one of a long list of ADAS aimed at supporting safe driving. The various ADAS adopt a broad approach to support the drivers. They get different feedback and the effects of the systems probably differ somewhat. Not all available ADAS systems will be presented here, but the three mentioned below are associated with each other. They can be arranged in a three-level hierarchy according to the precision and extent to which they are supposed to help the driver to improve road safety.

2.1.1 Event Data Recorder

The first level feedback regarding driving behaviour is an Event Data Recorder (EDR), also known as a 'Black Box'. The Black Box enables the car insurance company to place the responsibility in the event of an accident. It stores data a short time before, during and after any accident (Toledo, Musicant & Tsippy 2008).

The Danish insurance company, Alka, has been using EDR for a few years. A 40% discount on the insurance rate is offered if the car owner accepts the installation of an EDR in the car. Only with the car owner's acceptance can the insurance company get access to the data in the box. However, if the insurance company realises that the speed limit at the time of the accident has been violated by more than 5 km/h, it will increase the driver's self-payment by approximately € 134 per km/h in excess of the speed limit. Moreover, if the car owner refuses to hand over data to the insurance company it will increase self-payment by approximately € 4,500. So far there has been no documentation to indicate any effect of these boxes (Alka Forsikring 2008, Knudsen 2008). Globally, there is limited documentation of the effect of such systems. However, some reduction in accident costs has been found for fleet vehicles. Thus in companies where driving behaviour could result in dismissal or the like significantly reduced accident rates can be seen. A German trial involving young private drivers, on the other hand, has not found any effect of EDR (Heinzmann, Schade 2003 in Toledo, Musicant & Tsippy 2008). The limited effect might be due to the fact that the risk of extra self-payment is very low. The drivers do not believe that they will be involved in an accident, and accident statistics support them. Even if they are involved in many accidents the risk on the single trip is negligible (Várhelyi 1996, Nilsson 2004). So, it is plausible that monitoring has only insufficient effect on road safety unless serious financial penalties are included.

2.1.2 In-Vehicle Data Recorder

The second level is 'In-Vehicle Data Recorder' (IVDR), which allows feedback on the driver's behaviour. It could be in real time, afterwards on for example a webpage, or feedback from a driver's manager. Information could be about the actual speed, major decelerations, accelerations, turns, or similar activities, which might pose serious risks on the road network. Speed and position can be based on GPS data from moving cars denoted as Floating Car Data (FCD), but without connection to the actual road conditions. That is information about, for example, very high speed will be given regardless of the local speed limit (Toledo, Musicant & Tsippy 2008).

A few IVDR trials have been reported so far. In 1976, 224 police cars in Tennessee, USA were equipped with tachograph recorders with the aim of recording the drivers' driving behaviour. The measure was due to poor road accident statistics among the police officers. Application of the recording equipment was divided into three phases: 1: no feedback was given but driving was recorded. 2: feedback from colleagues was given, but inappropriate driving behaviour had no consequences for the individual police officer, and 3: an inspection team gave feedback. No effect on the number of incidents and on driving behaviour was found in the two first phases. In the third phase, however, traffic accidents were almost eliminated among the police officers (Larson et al. 1980). Also, the Icelandic postal service has had an IVDR system implemented, which collects FCD on speed, utilization, and position. Feedback was sent to the drivers weekly. Over a six-month period the result was 43% fewer accidents, leaving the level of severity out of account (Toledo, Musicant & Tsippy 2008). Furthermore, the insurance company Norwich Union has used an IVDR system to implement Pay-as-you-drive principles in calculating car insurance rates. The insurance rate was related to where and when driving had taken place, so high risk periods and places such as Saturday nights and downtown areas had a higher insurance price than other, safer places and times. No feedback was implemented regarding speed and speed limits. However, due to the lack of installation of ITS in the cars at manufacturing stage, Norwich Union has terminated their private car insurance discount system, while it still worked in commercial fleets (CompanyCarDriver 2008). A number of insurance companies in different countries have offered similar insurance schemes, some based only on the distance driven while others combine that with how and when the driving is carried out - as in the Norwich Union scheme (Victoria Transport Policy Institute 2010).

In the light of the found results, it seems plausible that monitoring has a strong effect when associated with serious financial penalties or work-related sanctions. No evidence has been found of a marked safety effect if the recording equipment is used for information purposes only. Hence, it is plausible that the same problems can be found for IVDR as for EDR when inappropriate driving behaviour has no consequences for the drivers.

2.1.3 Intelligent Speed Adaptation

The third level is ISA. The key issue here is real time map matching between the current position and the speed limit on the local road. The driver will receive feedback related to his/her actual speed and the speed limit on the road. Hence, a more precise and suited feedback is available. For an overview of the three levels of ADAS see Figure 2.1.

2.2 Intelligent Speed Adaptation principles

A number of ISA principles have been developed, depending on how the system was intended to affect driving behaviour, the purpose of the trial, and the technological options at the time of the trial. An overview of the ISA principles appears in Table 2.1 and will be expanded afterwards.

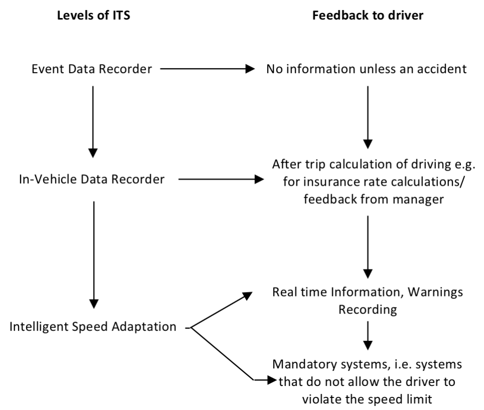


Figure 2.1. A proposed hierarchy of ADAS.

ISA can be *informative*. It informs the driver about the speed limit for a particular location, often by a display indicating the speed limit. The informative ISA is also known as *advisory* ISA. The information is available for the driver whether the speed limit has been violated or not. In some trials it is constantly activated (Madsen 2001, Carsten et al. 2008), while in others it only appears on request or in case of speeding (Regan et al. 2006b). In case of speeding no feedback is given and the safety effect is lower than for other ISA principles (Carsten, Tate 2005). ISA can also be *warning*, giving feedback if the speed limit is violated. The feedback can be in the form of flashes from a diode and/or from a display, auditory warnings or a *haptic throttle*[3] also known as *Active Accelerator Pedal* (AAP). The warning ISA can be combined with the informative one. See e.g. Carsten & Tate (2005) or Biding & Lind (2002). The display offers more options than does the diode. It normally shows the speed limit (informative), but often it is connected with some kind of reaction if speeding occurs too. In one trial, the display was not activated until speeding actually occurred and then it would flash if speeding continued (Regan et al. 2006b)[4]. Auditory warnings have been used, in some trials only as a beep in the event of a speed violation, while it has been more advanced in other trials. E.g. in the Danish *INFATI* ISA trial, a female voice message would say '50 - you are driving too fast' if the speed limit was violated on a road with a 50 km/h speed limit and si-

Table 2.1. ISA principles and feedback.

On/off function	Principle	Can be ignored	Feedback source
Voluntary or Mandatory	Informative/Advisory	Yes	Display
	Warning	Yes	Beep, Display, Flash, Voice Message, Haptic throttle
	Recording	Yes	Periodic feedback to driver, manager or insurance company
	Recording/Incentive	Yes	Payment depending on speed behaviour
	Intervening	No	Dead Throttle

[3] A haptic throttle is a throttle, which vibrates or becomes heavy to depress if the speed limit is violated.
[4] In modern GPS-based navigators, the same real time feedback is often available, but with the exception of one type (Paine 2008), the map quality has not been documented and at least in Denmark only part of the road network is covered and the quality and the speed limit information is lacking.

milarly for other speed limits (Lahrmann et al. 2007, Lahrmann, Madsen & Boroch 2001). Furthermore, ISA can be *recording*, which means that driving behaviour is logged. Floating Car Data (FCD) can be used for a number of purposes afterwards or in real time (Jamson et al. 2006, Lahrmann et al. 2007). ISA can also be *incentive*. Incentive ISA is based on recording ISA but is supplemented with a kind of reward or penalty system interrelating driving behaviour and reward/penalty. The reward in the case of no speeding could, for example, be a reduced insurance rate (Lahrmann et al. 2007). ISA systems can be *intervening*, which means that they affect driving behaviour physically. In most cases intervening ISA has been based on a *dead throttle*, which means that the driver cannot depress the throttle even with the intention of speeding. It can also be combined with systems, which reduce the fuel intake or exert pressure on the brakes in the case of speeding. See e.g. Carsten et al. (2008).

ISA can be divided into *voluntary* and *mandatory* systems. If it is possible for the driver to turn off ISA for a short or long period of time, it is voluntary and if not, it is mandatory (Jamson et al. 2006, Regan et al. 2006b). It should be noted that in some reports the terms *voluntary* and *mandatory* ISA are also used to describe if intervening systems are overridable or not.

In some ISA trials, the feedback systems have been a combination of two or more of these systems. In all, there are a number of feedback systems as well as a number of different levels of influencing systems. Before a presentation of the most central ISA results, a few definitions will be appropriate:

In this context, the word *speeding* is used to refer to driving above the set limit. In most cases, the set limit is equivalent to the highest speed allowed for a particular location. However, in some ISA trials, the limit is set at the speed limit plus a number of km/h, hence it is defined as speeding if the speed is above this slightly increased limit. In the *INFATI* trial, the limit was 5 km/h above speed limit while it was 2 km/h above speed limit in the Australian *TAC Safecar* trial and in two large-scale Swedish ISA trials (Regan et al. 2006a, Lahrmann, Madsen & Boroch 2001, Biding, Lind 2002).

The term *50 km road* is used to refer to a road with a speed limit of 50 km/h, and similarly with other categories of roads.

2.3 Experience of Intelligent Speed Adaptation

Well over 30 ISA trials have been carried out worldwide so far (Paine 2009). Different ISA equipment has been used, conditions have been different, and different groups of drivers have been involved (Jamson et al. 2006). It is not the purpose in this project to review all trials and all results. Focus is on efficiency, the possible operation modes of ISA, safety effects, any long-term effects, and the ability of the ISA systems to reach, on a voluntary basis, the road users who need most support (for example young drivers). The trial results are presented in topics instead of for each individual trial. The topics included are: feedback to the driver; effect on driving behaviour; effect on road safety; acceptance of ISA, and representativity regarding age distribution. Also, it should be noted that mainly results of long-duration ISA trials[5] are included in this review. An overview of the central ISA trials appears in appendix 1.

To ensure that sufficiently reliable references are used in the literature review, the following approaches were used: search was carried out in the databases *Web of Science*, *Scopus*, and *Transportation*. In addition, a number of books and reports were included as important references in the present field of research. In the databases, search was made using the words *Intelligent Speed Adaptation* or *Speed Limiter*, individually and in combination with *Safety* or *Road Safety* or *Traffic Safety*. Furthermore, research material was double-checked by searching authors who are central figures in the most significant ISA trials: *Biding, T.; Carsten, O.; Ehrlich, J.; Lahrmann, H.; Regan, M. A.; Várhelyi, A.,* and *Vlassenroot, S*. Other authors were involved in those trials, however, I am firmly convinced that the most significant trials will be well documented through the inclusion of the above-mentioned authors. Finally, references found during the ongoing research work have been included in the literature review when they seemed to be of sufficient relevance.

2.3.1 Feedback to the driver

Informative ISA showing the actual speed limit was in most cases carried out via a display (Jamson 2006). However, in several trials, it was combined with auditory and visual warnings if speeding. In the Swedish trial in *Borlänge* in 2000-2001, a display showing the speed limit was combined with auditory and visual feedback if speeding by more than two km/h over the speed limit occurred. The trial involved 400 cars (Biding, Lind 2002). Likewise, in the *INFATI* trial, involving 24 drivers, and in the Swedish trial in *Lidköbing*, involving 150 cars, informative ISA was combined with auditory and visual warnings (Madsen 2001, Biding, Lind 2002). Furthermore, in the Norwegian *Karmøy* trial involving 50 cars owned by young drivers, informative ISA was combined with auditory feedback (Berg, Bayer & Thesen 2008)[6]. In the French *LAVIA* trial, carried out 2003-2005, the first of three ISA periods was carried out using a display showing the speed limit, which would start flashing in case of speeding (Ehrlich et al. 2003). In the *INFATI* trial, the auditory feedback was a female voice message saying ‘50, you are driving too fast’, while in the above-mentioned Swedish and Norwegian trials, it was a tone message (Lahrmann, Madsen & Boroch 2001, Biding, Lind 2002, Berg, Bayer & Thesen 2008). One of the newest ISA systems is *SpeedAlert*. In this system, the user

[5] Trials comprising only a few or a single trip per driver are not presented here. In those trials notable results occurred too. However, the scope of this report being the effects of ISA applied over a certain period of time, it seems reasonable to exclude the short trials. Furthermore, it does not seem reasonable to expect drivers to be familiar with, for example, the haptic throttle after such a short time of use (Várhelyi et al. 2004).

[6] Results regarding the Karmøy trial will be presented cursorily in this section, due to the fact that no baseline period was included. Hence no effect of the application of the system could be estimated.

can set an alert at a predetermined number of kilometres above the speed limit. There are three threshold levels: 1: visual alert (SpeedAlert figure changes from black to red), 2: first level of beeping (one beep per second), and 3: second level of beeping (3 beeps per second). This ISA system now works under market condition in Australia (Smart Car Technologies Pty Ltd 2009)[7].

Informative ISA has also been combined with warning ISA in the form of AAP, which was activated in case of speeding. In *Lund*, Sweden (2001), 284 vehicles were equipped with AAP in combination with a display showing the speed limit (Várhelyi et al. 2004). The same function was used for 130 cars in *Lidköbing*[8]. In *Borlänge*, 10 out of 400 vehicles carrying a display showing the speed limit in combination with auditory and visual feedback were later equipped with a haptic throttle vibrating in case of speeding (Biding, Lind 2002)[9]. And also in the trial in *Ghent* in Belgium, 2002-2004, involving 34 cars and three buses, AAP and a display showing the speed limit were used (Vlassenroot et al. 2006). As in *Lund*, the speed limiter function could be used on a voluntary basis outside the test area (Várhelyi et al. 2004, Vlassenroot et al. 2006). AAP was also used as feedback in the *PROSPER* trials in Spain and Hungary (Adell, Várhelyi & Hjälmdahl 2008).

Furthermore, a few trials have used warning ISA without the informative element. In the large-scale trial in *Umeå*, in Sweden, 3,879 vehicles were equipped with warning ISA (Garvill et al. 2001) consisting of a diode, which would flash, and a tone message in case of speeding by more than 2 km/h above the limit (Biding, Lind 2002). In the Australian *TAC Safecar* trial, which was carried out in the Melbourne area 2003-2005, 15 drivers drove cars, which, among other things, were equipped with ISA[10]. The feedback system consisted of a display, a loudspeaker and AAP. ISA was only activated if the speed limit was violated by more than two km/h. The feedback worked in two steps: 1: the speed limit appeared in the display and a single auditory tone followed. If speeding continued, step 2 followed: two seconds later the display would be flashing and an upward pressure would occur on the AAP (Regan et al. 2006b). Besides the warning ISA, a *Speed request button* could be activated as well and the speed limit would temporarily appear in the display (Regan et al. 2006a).

Also, a number of trials with intervening ISA have been carried out. In the Dutch *Tilburg* trial (1999-2000), 20 cars and one bus were equipped with ISA. If the speed limit was violated, the fuel injection was closed (Loon, Duynstee 2001). i.e. dead throttle. Also in the *LAVIA* trial, the 102

[7] In November 2009, more than 10,000 units had been sold in Australia so far that year (Germanos 2009).

[8] Two different set-ups were used in Lidköping (Biding, Lind 2002).

[9] Two different set-ups were used in Borlänge due to supplier delay (Biding, Lind 2002).

[10] Besides ISA the cars were also equipped with FDW, which was tested alone and together with ISA. Only results achieved with ISA but without FDW activated are included in this review. In addition, daytime running light, seat belt reminder, and reverse collision warning were tested during the trial.

drivers of 20 cars drove with dead throttle in a sub period of the trial (Ehrlich 2002, Pianelli, Saad & Abric 2007). In the *ISA UK* trial (2006-2007) with 79 drivers involved, an enhanced version of the AAP was used. An upward pressure would be initiated when 90% of the speed limit was reached and would gradually increase towards the speed limit. In addition, the brake was activated electronically if the speed limit was violated by more than 2% (Carsten et al. 2008)[11].

In all the above-mentioned trials where a haptic or dead throttle was part of the feedback, a *kick down* function was included: the ISA feedback could be ignored in case of emergency situations or in case of overtaking manoeuvres (Regan et al. 2006a, Biding, Lind 2002, Várhelyi et al. 2004, Vlassenroot et al. 2006, Carsten et al. 2008). Where it was a haptic throttle, it was done by increased pressure on the accelerator, unlike in trials with intervening ISA. In the *ISA UK*, the *Tilburg*, and the *LAVIA* trials, the vehicles were therefore additionally equipped with opt-in and opt-out buttons giving the opportunity to deactivate ISA temporarily (Loon, Duynstee 2001, Ehrlich 2002, Carsten et al. 2008).

A substantial proportion of the ISA trials involved a recording element. In the *Borlänge* trial driving behaviour was recorded with 1 or 0.1 Hz, respectively, while driving was not recorded in *Lidköbing* nor in *Umeå* (Biding, Lind 2002). In the *INFATI*, *Karmøy*, and the *Ghent* trials, driving was also recorded with 1 Hz while it was 2 Hz in the *Tilburg* trial (Madsen 2001, Berg, Bayer & Thesen 2008, Vlassenroot et al. 2006, Loon, Duynstee 2001). In the *TAC Safecar* trial, the *PROSPER* trials, and in *Lund*, it was 5 Hz while it was as high as 10 Hz in the *ISA UK* trial (Regan et al. 2006b, Adell, Várhelyi & Hjälmdahl 2008, Carsten et al. 2008). Data logging frequency is a trade of between the handling of big amounts of FCD[12] and the potential precision of the subsequent data analyses. To the best knowledge of the author, the recording of driving behaviour in ISA trials has until a few years ago not been used for other purposes than documentation of the effects of ISA and scientifically related documentation for the same purpose.

A couple of trials included an incentive for avoiding speeding. In *Borlänge*, after the basic ISA trial ended, another trial of informative and warning ISA combined with incentive was carried out to try out a Usage Based Insurance (UBI) scheme. The 95 participants were offered a bonus of SEK 250 or 500 per month while any speeding would mean deduction of an amount from this bonus depending on the severity of the speed violation. The incentive scheme was active for three months[13] (Hultkrantz, Lindberg 2009). In

[11] It is, of course, debatable whether this system can be seen as a 'dead throttle' only due to its warning feedback below the speed limit. However, due to the fact that it is not overridable, it has been grouped with intervening systems.

[12] FCD regarding ISA is, if noting else is stated, identical with GPS data, i.e. data in which position and speed etc. are received from GPS satellites.

[13] It actually worked for three months, but winter weather during the last month made it impossible to measure any effect of ISA in this month (Hultkrantz, Lindberg 2009).

the Dutch *Belonitor* trial, 62 rental cars were equipped with warning ISA, among other things. Points, which were convertible into rewards donated by an insurance company, could be earned if both speeding and too short time headway were avoided. After a baseline period, incentive ISA was activated for 16 weeks, and incentives for avoiding speeding were reduced stepwise (Hattem, Mazureck 2006).

2.3.2 Effect on driving behaviour

Measuring the effect of ISA

The effect of ISA on driving behaviour has been measured in various ways in different ISA trials. Both the way of measuring the effect of ISA and the selection of FCD to be included in the estimations might affect the results.

In most ISA trials the total FCD fulfilling certain requirements are included when results are estimated. FCD could be distributed on speed limits, area use, and any ISA feedback, for instance ISA deactivated/ISA activated in various ways. All driving is thus included, even driving on roads where only a few ISA equipped vehicles had driven, and hence more reliable results could be expected than if only selected parts of the data were included. On the other hand also low speed driving due to congestions and in intersections is included, which might result in an underestimation of the effect of ISA.

Regarding some results of ISA, such as the *Lund* and the *PROSPER* trials, only data from participating vehicles driving in selected midblocks and spots were included in the results (Várhelyi et al. 2004, Adell, Várhelyi & Hjälmdahl 2008). If the selected spots and midblocks are located in areas where congestion and low-speed driving do not normally occur, the results might be reliable because the congestions would not confound the results. On the other hand it might be an issue if FCD from these selected spots are considered representative of the overall driving behaviour during the entire trial. Moreover, results from the *PROSPER* trials indicated that using FCD from selected spots only can result in unreliable results if the participating drivers drove within a large area or only used selected parts of the road network a little (Adell, Várhelyi & Hjälmdahl 2008). Results based on driving behaviour in selected spots only might therefore be hard to compare with results based on all collected FCD.

Mean speed shows the mean speed for driving in a certain period and includes all driving, also during congestion or idling. Unless other approaches are used to avoid congestion etc. in data, this measure often shows small or negligible effects of ISA on driving behaviour. Also, the results in many cases are significantly below the speed limit and hence the direct effect of ISA is not directly visible (Biding, Lind 2002). *Mean Free Flow Speed (MFFS)* means the driving speed when the vehicle in front has not affected the driver, i.e. under free flow conditions. *MFFS* is a useful way to measure the effect of ISA, because any driving which is slowed down by road furniture or other drivers is deducted so estimations are based only on the proportion of driving during which ISA can be expected to be efficient. The challenge of *MFFS* is to define which part of the FCD can be included as driven under free flow conditions. Considerations on *MFFS* are elaborated in the method section. *85 percentile speed* indicates what driving speed 85% of the total driving is below. It has been used to measure the effect of ISA in several trials. The advantage of the *85 percentile speed* is that it eliminates any bias from idling and congestion driving. Also, in several cases it has shown markedly more significant results than has *mean speed* (Regan et al. 2006a, Várhelyi et al. 2004, Carsten et al. 2008). On the other hand it might not show any effect on driving above the speed limit, because even without ISA activated some results show *85 percentile speeds* below the speed limit. See e.g. Várhelyi et al. (2004). Besides this, the *proportion of driving above the speed limit* or activation level of the ISA equipment shows the amount of driving which might be directly affected by ISA. This could be measured as the proportion of the *distance* driven above the speed limit (PDA) or the proportion of the *time* driven above the speed limit (PTA), which might give different results. This will be discussed later. Furthermore, according to Salusjärvi (1981) and Finch (1994) *speed variation* affects road safety substantially, the higher *speed variation*, the higher risk. When measuring the effect of ISA, two effects on driving behaviour result from reduced *speed variation*: less *speed variation* in general and a decrease in driving considerably above the speed limit as well as considerably below the speed limit because driving will be more concentrated on speeds near the speed limit. The latter can also explain why mean speed in some cases remains almost unchanged even though many trials have shown reduced *PDA* or *85 percentile speed*. Moreover, *transportation time* is normally compared to the distance driven, so the time use per km e.g. can be estimated.

General effects

Intervening ISA, i.e. the dead throttle combined with braking control as in the *ISA UK* trial, undoubtedly gives the most efficient feedback since speeding is impossible unless a deactivation button is available. However, the resistance to such systems is stronger than to other types of ISA feedback (Pianelli, Saad & Abric 2007, Várhelyi, Hjälmdahl & Almquist 2002, Päätalo, Peltola & Kallio 2001, Várhelyi, Comte & Mäkinen 1998). Warning ISA, too, has a substantial impact on driving behaviour. In the *INFATI* trial, it was found that a voice message in case of speeding was very efficient (Nielsen, Boroch 2001). In *Lund* and *Lidköbing*, it was found that feedback from flashing light combined with an auditory tone was almost as efficient as was the AAP (Biding, Lind 2002). In the *PROSPER* trials, AAP was in general more efficient than was the combination of visual and auditory feedback called *BEEP* (Adell, Várhelyi & Hjälmdahl 2008). Informative ISA alone might have some effect on speeding, however, it seems to be smaller than the effect of warning ISA. In the *Ghent* trial, driving behaviour with and without AAP but with the actual speed limit shown in a display under both conditions was compared. The effect of informative ISA was not documented, but there was a significant additional effect due to the AAP (Vlassenroot et al. 2006). Moreover, the impact of informative ISA only might decrease substantially over time (Klarborg et al. 2007). For a more thorough discussion of the effect of different types of feedback, see for example Várhelyi's *Dynamic speed adaptation based on information technology: a theoretical background* (1996).

Mean speed
In the *Tilburg* trial of intervening ISA, mean speed decreased substantially (Loon, Duynstee 2001). Also the *Ghent, Lund*, *Borlänge*, and the *PROSPER* trials showed markedly decreased mean speed. In the *Ghent* trial mean speed increased by 0.7 km/h and decreased by 1.1 km/h on 50 and 90 km roads, respectively. On 30 and 70 km roads, it remained unchanged (Vlassenroot et al. 2006). Regarding the *Ghent* results it should be noted that the participating drivers generally were rather conservative regarding speeding. In *Lund* mean speed was reduced by 3.7, 3.5, 2.7, 0.4, 0.9 km/h, on arterial 70 km street, dual carriageway; arterial 50 km street, dual carriageway; arterial 50 km street, single carriageway; main 50 km street; main 50 km street, mixed traffic, respectively, and an infinitesimal increase of 0.1 km/h occurred on central 30 km street. Only on carriageways and main streets with mixed traffic were the reductions statistically significant (Várhelyi et al. 2004). It should be noted that in *Lund* both results based on the entire driving and based on driving in selected midblocks and spots were used to estimate the effect of ISA. Thus the results presented for the trial are not directly comparable with each other in all cases. In *Borlänge*, mean speed was reduced by 0.6, 1.5, 3.0, and 3.4 km/h on 30 km, 50 km, 70 km, and 90 km roads, respectively. (Biding, Lind 2002). Results regarding the *Lund* and the *Borlänge* trials are concerning long term effects (> 5 months with ISA). In Spain, in the *PROSPER* trial, mean speed when driving with AAP was reduced by 3.9, 2.6, 2.5, 3.9 km/h on 30, 50, 80, and 120 km roads, respectively. For the similar road types but with BEEP, the reductions were 2.8, 1.4, 1.0, and 1.9 km/h, respectively - i.e. a markedly higher effect of AAP than of auditory and visual warnings in combination (Adell, Várhelyi & Hjälmdahl 2008). See table 2.2 and 2.3.

In the ISA UK trial, reduced mean speed due to ISA was likewise found. It was 1.6, 0.6, and 4.7 km/h for 30, 40, and 70 mph roads, respectively[14]. On the other road types there was also a reduction in mean speed but it was not statistically significant. Except on 70 mph roads, the reductions were smaller than found in most other trials (Carsten et al. 2008). The difference might be due to the fact that the British trial drivers drove more slowly from the

Table 2.2. The changed mean speed due to ISA (km/h) in *Ghent*, *Borlänge* and the two *PROSPER* trials.

	Speed limit				
Road type	30 km/h	50 km/h	70/80 km/h	90 km/h	110/120 km/h
Borlänge	-0.6	-1.5	-3.0	-3.4	-
Ghent	0.0	0.7	0.0	-1.1	-
PROSPER, AAP	-3.9	-2.6	-2.5	-	-3.9
PROSPER, BEEP	-2.8	-1.4	-1.0	-	-1.9

[14] The results, but not the road type name from the *ISA UK* trial have been converted from miles into kilometres (1 mile = 1.609 km) and will be henceforth.

Table 2.3. The changed mean speed due to ISA (km/h) in *Lund*.*indicates statistically significant changes.

	Road type					
Road type	Arterial 70 km street, dual carriageway	Arterial 50 km street, dual carriageway	Arterial 50 km street, single carriageway	Main 50 km street	Main 50 km street, mixed traffic	Central 30 km street
Lund	-3,7*	-3,5*	-2,7*	-0,4	-0,9*	0,1

Table 2.4. The changed mean speed due to ISA (km/h) in *ISA UK*. *indicates statistically significant changes.

	Speed limit					
Road type	20 mph roads	30 mph roads	40 mph roads	50 mph roads	60 mph roads	70 mph roads
ISA UK	-1,5	-1,6*	-0,6*	-0,7	-0,7	-4,7*

starting point than the drivers in many other trials (Biding, Lind 2002, Várhelyi et al. 2004, Adell, Várhelyi & Hjälmdahl 2008, Carsten et al. 2008). See table 2.4.

Mean Free Flow Speed
In the *TAC Safecar* trial where, in addition to ISA, the cars were equipped with FDW, free flow conditions were assumed if there were 3 or more seconds' headway (Regan et al. 2006b). The MFFS due to ISA was reduced by 1.1, 1.4, and 0.9 km/h on 60, 80, and 100 km roads, respectively. Reductions in MFFS were found for 50 and 70 km roads but they were not statistically significant. (Regan et al. 2006b). To my best knowledge, no results regarding ISA and MFFS have been published apart from the *TAC Safecar* trial results. See table 2.5.

85 percentile speed
In the *INFATI* trial, the reduction of the 85 percentile speed was significant. In centre areas where speeding was limited the effect of ISA was the smallest but still amounted to a marked reduction of approximately 2 km/h. On the other hand it was more significant on roads in suburban and rural areas where the 85 percentile speed was reduced by approximately 4 and 7 km/h, respectively (Lahrmann, Madsen & Boroch 2001). See table 2.6.

In the *Ghent* trial, a markedly smaller but still remarkable reduction in the 85 percentile speed on most road types appeared. It was reduced by 2.5, 0.4, 2.5, and 2.5 km/h for 30, 50, 70, and 90 km roads, respectively. (Vlassenroot et al. 2006). In the Spanish part of the *PROSPER* trial, it was found that the 85 percentile speed de-

Table 2.5. The changed MFFS due to ISA (km/h) in the *TAC Safecar* trial. * indicates statistically significant changes.

	Speed limit				
Road type	50 km/h	60 km/h	70 km/h	80 km/h	100 km/h
TAC Safecar	-0.7	-1.1*	-0.9	-1.4*	-0.9*

Table 2.6. The changed 85 percentile speed due to ISA (km/h) in the *INFATI* trial.

Area type	City centre	Suburban areas	Outside built-up areas
INFATI	-2.0	-4.0	-7.0

creased by 7.2, 4.3, 6.5, and 2.2 km/h on 30, 50, 80, and 120 km roads, respectively, when AAP was used. When BEEP was used, the effect was lower, with reductions of 2.8, 1.4, 1.0, and 1.9 km/h, respectively. Hence, as for mean speed, a more marked effect seems to appear from AAP than from BEEP (Adell, Várhelyi & Hjälmdahl 2008). In the *TAC Safecar* trial, the 85 percentile speed was reduced by 2.3, 2.7, 2.0, and 1.6 km/h after ISA implementation on 50, 60, 70, and 100 km roads, respectively. Also a not statistically significant reduction on 80 km roads was found (Regan et al. 2006b). See Table 2.7.

In the *Lund* trial, markedly reduced 85 percentile speed was likewise found. It decreased by 7.6, 6.1, 5.8, 2.2, 1.0, and 1.4 km/h on arterial 70 km street, dual carriageway; arterial 50 km street, dual carriageway; arterial 50 km street, single carriageway; main 50 km street; main 50 km street, mixed traffic; and central 30 km street, respectively. Regardless of the big reduction in 85 percentile speed on some road types none of these results were statistically significant (Várhelyi et al. 2004). Finally, in the *ISA UK* trial, the 85 percentile speed was reduced statistically significant by 2.4, 3.9, 3.4, 3.2, and 6.9 km/h on 20, 30, 40, 50 and 70 mph roads, respectively. Finally, a not statistically significant reduction by 1,3 km/h was obtained on 60 mph roads (Carsten et al. 2008). See table 2.8 and 2.9.

Proportion of driving above the speed limit

In the *Ghent* ISA trial, PDA was reduced by 3.1, 1.6, 5.0, and 9.7 percentage points (%) on 30, 50, 70, and 90 km roads, respectively (Vlassenroot et al. 2006). In *Lund* the reduction in PDA after long-time use of ISA was 6.9, 12.8, and 13.9% on 30,

Table 2.7. The changed 85 percentile speed due to ISA (km/h) in *Ghent*, the two *PROSPER* trials in Spain and in the *TAC Safecar* trial. * indicates statistically significant changes regarding the *TAC Safecar* trial.

Road type	30 km/h	50 km/h	60 km/h	70/80 km/h	90 km/h	100/110/120 km/h
Ghent	-2,5	-0,4	-	-2,5	-2,5	-
PROSPER, AAP	-7,2	-4,3	-	-6,5	-	-2,2
PROSPER, BEEP	-3,6	-3,0	-	-5,0	-	-0,4
TAC Safecar	-	-2,3*	-2,7*	-2,0*	-	-1,6*

Table 2.8. The changed 85 percentile speed due to ISA (km/h) in *Lund*. No changes were statistically significant.

	Road type					
Road type	Arterial 70 km street, dual carriageway	Arterial 50 km street, dual carriageway	Arterial 50 km street, single carriageway	Main 50 km street	Main 50 km street, mixed traffic	Central 30 km street
Lund	-7.6	-6.1	-5.8	-2.2	-1.0	-1.4

Table 2.9. The changed 85 percentile speed due to ISA (km/h) in *ISA UK* trial. * indicates statistically significant changes.

	Speed limit					
Road type	20 mph	30 mph	40 mph	50 mph	60 mph	70 mph
ISA UK	-2.4*	-3.9*	-3.4*	-3.2*	-1.3	-6.9*

Table 2.10. The changed PDA due to ISA (%) in *Ghent*, *Lund* and *Borlänge*.

	Speed limit				
Road type	30 km/h	50 km/h	70 km/h	90 km/h	110 km/h
Borlänge	-3.4	-11.8	-9.4	-11.4	-7.4
Ghent	-3.1	-1.6	-5.0	-9.7	-
Lund	-6.9	-12.8	-13.9	-	-

50, and 70, km roads, respectively. In *Borlänge*, the PDA after long-term use of ISA was reduced by 3.4, 11.8, 9.4, 11.4, and 7.4% on 30, 50, 70, 90 and 110 km roads, respectively. Regarding the trials in *Lund* and *Borlänge* it is not stated if the reductions were statistically significant (Biding, Lind 2002). See table 2.10.

Furthermore, in the *ISA UK* trial, the reduction was 7.1, 7.1, 6.1, and 11.1% on 30, 40, 50 and 70 mph roads, respectively. In addition, a not statistically significant reduction was found for 60 mph roads while on 20 mph roads the reduction was infinitesimal (Carsten et al. 2008). See table 2.11.

Moreover, in the *TAC Safecar* trial, the PTA (speed limit + 2 and 5 km/h, respectively), was calculated. The PTA + 2 km/h was reduced by 12.6, 10.8, 12.7, and 11.8% on 60, 70, 80, and 100 km roads, respectively. In addition a not statistically significant reduction on 50 km roads was found. Regarding the PTA + 5 km/h the results were lower. The reduction was 5.9, 8.8, 6.9, 8.4, and 5.4% on 50, 60, 70, 80, and 100 km roads, respectively. All values regarding the *TAC Safecar* trial were concerning free flow driving (Regan et al. 2006b). See table 2.12.

It should be noted that the PTA differs substantially from the PDA in most cases. Hence, one should be careful in making a comparison between these two types of data. This aspect will be further elaborated on in Section 4.2.

Speed variation

In the *Tilburg* trial a more homogeneous speed pattern was archived (Loon, Duynstee 2001). In the *Ghent* trial, Standard Deviation (SD) was reduced by 1.2, 0.3, 0.2, and 1.7 km/h on 30, 50, 70, and 90 km roads, respectively (Vlassenroot et al. 2006). In the *PROSPER* trial in Spain, the reductions in SD regarding AAP were by

Table 2.11. The changed PDA due to ISA (%) in the *ISA UK* trial. *indicates statistically significant changes.

	Speed limit					
Road type	20 mph	30 mph	40 mph	50 mph	60 mph	70 mph
ISA UK	-1.1	-7.1*	-7.1*	-6.1*	-2.2	-11.1*

Table 2.12. The changed PTA due to ISA (%) in the *TAC Safecar* trial. *indicates statistically significant changes.

	Speed limit				
Road type	50 km/h	60 km/h	70 km/h	80 km/h	100 km/h
TAC Safecar (limit + 2 km/h)	-8.2	-12.6*	-10.8*	-12.7*	-11.8*
TAC Safecar (limit + 5 km/h)	-5.9*	-8.8*	-6.9*	-8.4*	-5.4*

Table 2.13. The changes in speed variation due to ISA (km/h) in *Ghent*, the two *PROSPER* trials in Spain and in the *TAC Safecar* trial. * indicates statistically significant changes regarding the *TAC Safecar* trial.

Road type	30 km/h	50 km/h	60 km/h	70 km/h	80 km/h	90 km/h	100/120 km/h
Ghent	-1.2	-0.3	-	-0.2	-	-1.7	-
PROSPER, AAP	-1.5	-0.7	-	-	-3.2	-	4.0
PROSPER, BEEP	-0.7	-0.8	-	-	-4.0	-	2.7
TAC Safecar	-	-0.8*	-1.1*	-1.0*	-1.1*	-	-0.4*

1.5, 0.7, and 3.2 km/h on 30, 50, and 80 km roads, respectively. Regarding BEEP for similar road types the reduction was 0.7, 0.8, and 4.0 km/h, respectively. On 120 km roads both types of feedback resulted in an increased SD. It should be noted that while a much higher effect of AAP than of BEEP regarding mean speed and 85 percentile speed appeared, the same clear difference cannot be found regarding reductions in SD (Adell, Várhelyi & Hjälmdahl 2008). Also in the *TAC Safecar* trial SD was reduced by 0.8, 1.1, 1.0, 1.1, and 0.4 km/h on 50, 60, 70, 80, and 100 km roads, respectively. All results were based on free flow driving and were statistically significant (Regan et al. 2006b). See table 2.13.

It was found in the *Lund* trial that SD was reduced by 5.0, 1.7, 2.4, 1.4, 0.7, and 3.2 km/h on arterial 70 km street, dual carriageway; arterial 50 km street, dual carriageway; arterial 50 km street, single carriageway; main 50 km street; main 50 km street, mixed traffic; and central 30 km street, respectively (Várhelyi et al. 2004). Regarding the *Borlänge* trial it was estimated that SD was reduced by 20-25% compared to 30-40% in *Lund*, hence the AAP had a more marked effect than had the combination of visual and auditory feedback (Biding, Lind 2002). See table 2.14.

Besides this, in the *ISA UK* trial the speed distribution on 30 and 70 mph roads was changed toward a substantially higher proportion just below and above the speed limit, i.e. a reduced speed variation (Carsten et al. 2008).

Driving time

In *Lund*, transportation time decreased marginally by 0.6% in total. On 30 km streets it decreased by 5.4% while it increased slightly on 50 and 70 km roads by 0.9 and 1.2%, respectively (Várhelyi et al. 2004). In the *TAC Safecar* trial it was found that driving time while commuting remained virtually unchanged when driving was affected by ISA (Regan et al. 2006a).

Effect over time and long-term effect

Long-term effects are here defined as by Várhelyi et al. (2004) and are concerning more than 6 months. In the *Lund* trial it was found that the effect of ISA was reduced over time although driving behaviour remained substantially safer than

Table 2.14. The changes in speed variation due to ISA (km/h) in *Lund*.

	Road type					
Road type	Arterial 70 km street, dual carriageway	Arterial 50 km street, dual carriageway	Arterial 50 km street, single carriageway	Main 50 km street	Main 50 km street, mixed traffic	Central 30 km street
Lund	-5.0	-1.7	-2.4	-1.4	-0.7	-3.2

it was before the drivers tried ISA (Várhelyi et al. 2004, Várhelyi, Hjälmdahl & Almquist 2002). Based on the total FCD collected in *Lund* the PDA on 30 km roads was reduced by 14.1 and 6.9% for short-term and long-term use, respectively. For 50 km roads the same values were 15.0 and 12.8%, respectively, while they were 18.1 and 13.9%, respectively on 70 km roads (Biding, Lind 2002). The same pattern was found regarding *Borlänge*. On 30 and 50 km roads the reductions changed from 9.6 to 3.4% and from 16.4 to 11.8%, respectively. On 70 and 90 km roads values decreased from 13.0 to 9.4% and from 16.7 to 11.4%, respectively. Moreover, on 110 km roads the reduction was changed from 9.5 to 7.4%, respectively (Biding, Lind 2002). See table 2.15.

Furthermore, in the *Ghent* trial it was found that even though AAP reduced speeding, the effect decreased month by month (Vlassenroot et al. 2006). A similar trend was found in the *Karmøy* trial of informative, warning and recording ISA. Despite seasonal fluctuations, a decreasing effect of the ISA equipment over time was found (Berg, Bayer & Thesen 2008).

Moreover, in the Swedish incentive-based ISA trial, the drivers were randomly assigned into two-by-two treatment groups, with different participation bonus and penalty levels, and two control groups (high and low participation bonus, but no penalty). Feedback was given at the end of each month. In the first month, substantial reduced speeding was found for all groups of drivers. However, only where speeding was associated with penalties did the effect remain during the next month. Still, there was no clear connection between either the size of the penalty or the size of the bonus and the effect on speeding (Hultkrantz, Lindberg 2009). In the incentive-based ISA trial, *Belonitor*, the PDA was likewise markedly reduced by 18% but over time the effect decreased[15]. It was uncertain whether or not the decrease was caused by the reduced incentives. However, after deactivation of the equipment no lasting effect was found (Hattem, Mazureck 2006).

2.3.3 Effect on road safety

Measured effect on road safety

Even though most ISA trials have shown considerable effects on speeding, the number of cars in the trials has with one exception been far too low to measure any

Table 2.15. The short and long-term effects on PDA due to ISA (%) in *Lund* and *Borlänge*.

	Speed limit				
Road type	30 km/h	50 km/h	70 km/h	90 km/h	110 km/h
Lund, short-term	-14.1	-15.0	-18.1	-	-
Lund, long-term	-6.9	-12.8	-13.9	-	-
Borlänge, short-term	-9.6	-16.4	-13.0	-16.7	-9.5
Borlänge, long-term	-3.4	-11.8	-9.4	-11.4	-7.4

[15] It should be noted that the rewards were only given if sufficient time headway (1.3 seconds) was available. It might have affected the results (Hattem, Mazureck 2006). In the *TAC Safecar* trial activated FDW resulted in a higher effect of ISA than without FDW activated (Regan et al. 2006b).

real road safety effect of ISA. In *Umeå*, where 3,879 mainly privately owned vehicles were equipped with warning ISA, an effect could be measured. The number of cars involved in the trial corresponded to almost 10% of the vehicles in Umeå (Garvill et al. 2001). Even though it is estimated that approximately 60% of the vehicles in the area in question need to drive with ISA before the full safety effect can be expected and at least 20-25% need to drive with ISA before a considerable effect can be reached (Jamson et al. 2006, Archer, Åberg 2001), there were indications of effect on the road safety in Umeå. There was a reduction in the number of fatality and injury accidents of 5 to 7% in built-up areas compared to the national tendency. The reduction was, however, uncertain (Biding, Lind 2002).

Estimated safety effects

Várhelyi (1996) estimated that if an ISA system precluding speed violation, i.e. dead throttle or something similar, was fully implemented, the number of injury accidents would decrease by 24 to 42%. These results were based on changed driving behaviour and on Nilsson's Power Model (2004). By the same approach but based on the results of the *Lund* trial it was estimated that the number of injury accidents would decrease by 18 to 25% on arterial roads and slightly less on other road types in built-up areas[16]. Regarding fatal accidents the reduction was estimated at 23 to 32% if all vehicles were equipped with ISA. Taking into account other effects of ISA than reduced speed, a more comprehensive result based on all FCD from the *Borlänge* and from the *Lund* trials appears. It included reduced speed variation and better traffic behaviour in general. Hence, it was found that the number of injury accidents could be reduced by 20 to 25% if all vehicles in the area were equipped with ISA (Biding, Lind 2002). Carsten and Tate (2005) estimated that the safety effect, depended on whether ISA was advisory, voluntarily intervening, or mandatorily intervening, was 10, 10, and 20% reduction, respectively, regarding injury accidents. The effect was 15, 15, and 29% reduction, respectively, regarding injury and fatal accidents, and 18, 19, and 37% reduction, respectively, regarding fatal accidents. If variable or dynamic speed limits were used, an even higher safety effect of ISA could be expected (Carsten, Tate 2005)[17]. Moreover, during the *TAC Safecar* trial it was found that if ISA was rolled out, serious injury accidents could be reduced by 4.76, 5.81, 4.18, 5.39, and 2.84% on 50, 60, 70, 80, and 100 km roads, respectively. Regarding fatal accidents the reductions were estimated to 6.29, 7.68, 5.54, 7.12, and 3.77% for the same road types, respectively (Regan et al. 2006b). In the *TAC Safecar* trial the relatively small effect might be due to two reasons: 1: there was major focus on speeding in Victoria, Australia during the trial, which it is reasonable to believe reduced speeding dur-

[16] On basis of the Lund trial estimations of safety effects were both made regarding driving on midblocks only (Várhelyi et al. 2004) and on the basis of the entire driving on a certain road type (Biding, Lind 2002).

[17] Variable speed limits are speed limits, which are reduced for example during rush hours, near schools in the mornings and afternoons etc. Dynamic speed limits will be decreased due to worsening weather conditions, incidents on the road network etc. (Carsten, Tate 2005).

ing the period in general, and 2: none of the drivers were positive towards speeding (Regan et al. 2006b, Triggs 2008).

2.3.4 Acceptance of ISA

In the four Swedish large-scale trials the participating drivers were in general more positive towards ISA than were the average drivers. However, over time the share of drivers who found a deactivation device necessary, increased (Biding, Lind 2002). In addition, in *Umeå* it was found that the test drivers were more positive towards the combination of visual and auditory feedback, which was what they tried in the ISA trial, than they were towards informative ISA. They were least positive towards AAP and dead throttle. The average non-participating drivers had swapped the two first mentioned, but were statistically significantly less positive towards all types of ISA equipment than were the participating drivers (Garvill et al. 2001). In the *LAVIA* trial the drivers shared the same ranking of ISA types. Also, it was found that 55% of the participating drivers were positive before the trial started. This proportion increased to 70% regarding advisory ISA but decreased again to 45 and 38% regarding voluntary and mandatory intervening ISA, respectively (Pianelli, Saad & Abric 2007). Furthermore, the acceptance of ISA was measured during a number of trials, showing markedly changed levels of acceptance within these periods. Thus, in the *Tilburg* trial the drivers became somewhat more negative towards intervening ISA after the trial than they were before ISA was activated. However, while the drivers were slightly more positive towards ISA than the general population in the province, the population in the local area of the ISA trial were the most positive - an attitude that also became more negative over time (Loon, Duynstee 2001). Similar patterns could be found in the *TAC Safecar* trial where both the ISA drivers and the control drivers found ISA significantly less useful after the trial than before. There was no clear reason for the decreasing satisfaction in the control group (Regan et al. 2006b). In the *ISA UK* trial, however, the ratings of satisfaction improved over time while the rating of usefulness was high during the entire trial. Satisfaction decreased after activation of ISA. After long-term driving with ISA the attitude became more positive, but satisfaction became most positive after the ISA trial had ended (Carsten et al. 2008). However, it should be noted that even though the rating of satisfaction increased, it was still closer to neutral than positive. In general, ratings were positive towards the usefulness of ISA, dipping after a short time of ISA but then increasing again (Carsten et al. 2008). In the *Ghent* trial, attitudes to ISA similar to the ones found in the *ISA UK* trial appeared. Again the drivers found ISA more useful than satisfactory, and they generally found it more satisfactory after the trial (Vlassenroot et al. 2006). It should be noted that the participating Belgian drivers found ISA more satisfactory than did their British counterparts.

2.3.5 Representativity regarding age distribution

In the *TAC Safecar* trial the drivers were equally distributed on age groups except regarding the oldest group (55-64 years old) who were underrepresented. However, no drivers under 25 years old were allowed to participate in the trial and the youngest driver was 29 years old (Regan et al. 2006a, Regan et al. 2006b). In the large-scale trial in *Umeå*, the mean age of the participating drivers was six years older than it was for the control drivers (Garvill et al. 2001). An almost equivalent divergence in age was found regarding the drivers in the *Lidköping* trial (Biding, Lind 2002). In *Lund* the youngest age group was considerably underrepresented, they were more negative towards ISA and had a higher dropout rate than the average drivers in the trial (Várhelyi et al. 2004, Adell, Várhelyi 2008). In general, in the four large-scale trials in Sweden it was found that the youngest drivers were underrepresented in many cases. Having older cars than the average drivers, their cars could not often be fitted with ISA equipment (Biding, Lind 2002). Also, in the *Ghent* trial the young male drivers (18 to 24 years old) were underrepresented (Vlassenroot 2004). In the *ISA UK* trial age distribution was reasonable fair, but no drivers below 22 years old took part in the trial (Carsten et al. 2008). Likewise, in the *INFATI* trial it turned out to be impossible to recruit sufficient participants younger than 30 years old (Nielsen, Boroch 2001).

2.4 Summary and supplementing considerations

Various kinds of feedback from ISA equipment have been studied. Intervening ISA resulted in speeding virtually disappearing unless an override function was implemented. Informative ISA, on the other hand, seems to have rather little effect on speeding. The effect was in most cases higher when information was combined with various kinds of warnings in the case of speed violation. In the *PROSPER* trial it was found that AAP had a considerably higher effect than the combination of visual and auditory feedback regarding mean speed and 85 percentile speeds but not regarding speed distribution. In the *Borlänge* and *Lund* trials it was found that AAP and the combination of visual and auditory feedback had almost the same effect on driving behaviour, but with a slightly better effect of AAP. However, Vlassenroot (2006) found that, in the case of speed violation, the AAP used did not provide sufficient counter pressure to prevent speeding. In the *INFATI* trial it was found that auditory warnings and a flashing diode in combination with informative ISA had a significant effect on driving behaviour. Much smaller effects were found from warning ISA in the *TAC Safecar* trial, but it might have been due to the fact that there was major focus on speeding in Victoria during the trial, and that the drivers were quite conservative. As a general rule, the higher the speed limit, the higher the effect of ISA. However, on roads with low speed limits (30 km roads/20 mph roads) driving behaviour seems to be affected differently from one ISA trial to another. The same tendency can be seen regarding motorways (110, 120, and 130 km roads). Moreover, in the majority of the trials, it was found that the 85 percentile speed decreased more than did the mean speed - thus, reduced speed deviation and hence a positive safety effect besides the reduced high speeds, could be expected from ISA. Many ISA trials had shown significant results regarding speeding, but results differ from one trial to another, and one should be careful about benchmarking. Different types of ISA equipment were used as well as different approaches for measuring the effect, but also different driving cultures and other elements might have affected the results. After long-term use of ISA the effect in general decreases. However, the amount of speeding was in most trials still kept far below the level reached without ISA, as long as ISA was active. Incentive for drivers to avoid speeding seems to increase the effect and make it last longer, however, the size of the incentives seems to be less important. In a few trials, the effect of ISA on transportation time was studied. Even though it reduces speeding substantially, ISA has virtually no effect on transportation time.

The safety effects of ISA are considerable. It was estimated that informative ISA can reduce the number of injury accidents by 10%, while the reduction in fatal accidents was estimated at 18%. Most estimation suggested a reduction in the number of injury accidents of 18 to 25% when AAP or similar efficient ISA equipment was used. However, lower estimates were found for less busy road types. Regarding intervening ISA, the estimated effects are a reduction by between 23 and 42%, and an even bigger reduction can be archived if variable or dynamic speed limits are implemented. Moreover, when approximately 10% of the cars in *Umeå* were equipped with warning ISA, an uncertain reduction of 5 to 7% in the number of fatality and injury accidents on roads in built-up areas was reached.

The studies of attitudes towards ISA were carried out in a number of different ways. Therefore, one should be careful when comparing the drivers' experiences from different trials. However, where the attitudes among ISA drivers and non-ISA drivers were compared it was in most cases found that participating drivers were more positive towards ISA than other drivers. Also, it was found that the more intervening an ISA system was, the lower was the acceptance of it. Furthermore, in studies where the rating of usefulness and satisfaction was the focus of interest, usefulness was found to be higher than satisfaction. This might mean that the drivers would like ISA to be used by some groups of drivers, but not by themselves. The latter fits well with the results of more general studies of attitude to driving behaviour and risk, which also show discrepancy between how people assess their own driving compared to other drivers'. E.g. Várhelyi (1996) found that a clear majority (76%) of Swedish road users found that it was less risky if no one violates the speed limit. However, only 36% found that the same problem was associated with their own speed limit violations. Also, in the European questionnaire-based study *SARTRE III*, on average 63% of the respondents found that their driving behaviour was less dangerous than the average driver's (Cauzard 2004). Furthermore, in the *Belonitor* trial, 11% of the respondents saw speeding as a social problem, but only 2% saw it as a personal problem (Hattem, Mazureck 2005). Obviously, not all these statements can be reliable. Driver attitudes combined with the significantly higher rating of usefulness than of satisfaction among drivers in some ISA trials are presumably the key reason why ISA has not caught on among the general public so far. In a number of trials, the youngest drivers were underrepresented for various reasons. Thus, in one trial the drivers had to be at least 25 years old. Also, low interest and high drop out rates have been found regarding young drivers. Furthermore, young drivers own older vehicles in which integration of ISA is difficult, which resulted in a lower proportion of young drivers in some of the Swedish ISA trials.

Reliability of the results
Even though most results of ISA were tested regarding statistical significance, there might be an issue regarding reliability of the results. In some trials the number of participating drivers was low (15 in the *TAC Safecar* trial, 20 in each of the *PROSPER* trials, and 24 in the *INFATI* trial) (Regan et al. 2006b, Adell, Várhelyi & Hjälmdahl 2008, Lahrmann, Madsen & Boroch 2001). The small groups of drivers might yield less reliable results because a single driver reacting differently could affect the results more than if the group of drivers was big. On the other hand regarding most trials it was found that the drivers who needed ISA most, e.g. young novice drivers, were underrepresented. Also, it was found in several trials that the participants were more positive towards ISA than was the average driver. Despite this possible bias, it seems reasonable to consider results based on a low number of drivers as reliable. The fact is that, according to studies, most drivers have more or less the same attitude to speeding and speed limits. Also the fact that almost all results of ISA are consistent with each other (positive effect of ISA on speeding) indicates that the results are reliable. Another issue is whether a penetration rate of 100% for ISA will result in the same total effect on driving as it did for the participating drivers. On the one hand there might be a bigger effect because the average driver is liable to speed more than the participating drivers. On the other hand there might be a reduced effect because the average driver has a lower acceptance of ISA than have the participating drivers.

2.5 Initiating problem identification

A large number of ISA trials have been carried out with promising results. The methodology, equipment and recruitment procedures have been very different but the overall effect on speeding has been noticeable and positive. A fundamental hypothesis in many ISA projects seems to be that motorists would like to comply with speed limits but find that, in practice, complying can be difficult in a modern, comfortable car. Therefore, the purpose of ISA is to support the motorist in choosing the proper speed. The assumption is that speeding will be avoided, as drivers who receive such support will no longer violate the speed limits. Most ISA trials have supported the hypothesis: speed decreases and most users say that they found ISA very useful (Vlassenroot et al. 2006, Adell, Várhelyi & Hjälmdahl 2008, Carsten et al. 2008). The latter might also be caused by the fact that the drivers in some ISA trials were offered a free car during the trial period. See for example (Carsten et al. 2008, Ehrlich et al. 2003). Free cars may have affected the users' attitude to ISA positively. However, despite the general effectiveness of ISA and users' approval of the systems, only easily ignorable warning ISA, in the form of *SpeedAlert*, has been put on the market, and only since late 2008. Besides this, there are no consequences for ignoring the feedback (Paine 2008). Moreover, it has been found in a number of trials that the effect of ISA decreases over time (Biding, Lind 2002, Várhelyi et al. 2004, Vlassenroot et al. 2006).

Another issue is that young drivers were considerably underrepresented in a number of ISA trials. And they are found to have a more negative attitude towards ISA than other participating groups in e.g. the *Lund* trial. Also Young, Regan, and Mitsopoulos (2004) found that young drivers in general had a low acceptance of ISA, in particular when ISA consisted of speed limiting devices.

Moreover, in the cases where test-driving volunteers were studied, it was in most cases found that the drivers who decided to participate in ISA were more risk averse and more positive towards ISA than the drivers who did not. Much seems still to indicate that more than goodwill is needed before drivers who need ISA most (e.g. young drivers and drivers of commercial vehicles) will voluntarily drive with it (Jamson 2006).

The above-mentioned experiences give rise to two questions:

- When almost everybody is so positive towards ISA, why was it not put on the market on a large scale several years ago? and,
- why have those who need ISA most to make their driving safer, e.g. young drivers, been underrepresented or virtually absent in most ISA trials so far?

Could it be that although the majority of the drivers participating in the trials found ISA rather useful, they found it considerably less satisfactory to actually drive with it? In other words, they were positive towards the concept of ISA but found it of no relevance to their own driving. The latter is confirmed by the fact that the majority of the drivers generally had a higher opinion of their own driving skills than of the average driver's as Cauzard and Hattem & Mazureck also found. It is thus plausible that most drivers see no need for an ISA device in their own car. In the light of this, it is likewise plausible that an economic incentive related to speeding behaviour could be the determining factor that opens the market to ISA on a large scale.

Therefore, the set target for the two Danish ISA trials was to develop an efficient incentive-based ISA system on a commercial basis targeting young drivers and commercial drivers. Consequently, the underlying hypothesis guiding essential aspects of the development of the said system was that incentive related to driving behaviour would result in:

- Significantly reduced speeding among the participating drivers,
- lasting effect of ISA over time (up to three years), and
- easier recruitment among young drivers.

3 Research framework

3.1 Incentive

Incentive is a central part of the two Danish ISA trials. Therefore a brief introduction follows explaining how incentive affects behaviour in general and driving behaviour in recorded cases.

Incentive is a factor, which encourages someone to carry out a certain action. Basically, incentive can be *positive* or *negative*, and it can be *financial* or *moral* (Kane et al. 2004). By positive incentive is meant that an individual (or group) is rewarded if a desired action is carried out, while in the case of negative incentive a penalty is applied if the desired action is not carried out. By financial incentive is meant money or other effects, which can be valued financially. Financial incentives might be cash payments, lotteries, and coupons for free as well as goods, services, and gifts at reduced prices (Kane et al. 2004). Moral incentive is non-material, e.g. praise or social attention (Hagenzieker, Bijleveld & Davidse 1997).

A number of factors influence the effect of incentives. Thus, there are marked differences between *short* and *long-term* effects, short-term effects being often greater than long-term ones (Hultkrantz, Lindberg 2009, Kane et al. 2004, Hagenzieker, Bijleveld & Davidse 1997). It is especially clear when it comes to single activities such as immunisations vs. long-term efforts such as permanent change in behaviour (Kane et al. 2004, Hagenzieker, Bijleveld & Davidse 1997). The latter used a meta-analytic approach on 34 studies regarding seatbelt use. Short-term results were an increase of seat belt use of 20.6 percentage points, while the long-term effect was 13.7 percentage points.

Lasting effects are more uncertain. Kane et al. (2004) studied incentive effects in the area of health care including 47 randomised trials. In a few of these the lasting effect was studied, and no lasting effect was found. On the other hand, Hagenzieker et al. (1997) found that there was a minor but lasting effect on seatbelt use. It is possible that while it is hard to reach an effect when a constant change in behaviour is needed, e.g. loss of weight or smoking cessation, it is easier when it comes to short-term activities such as seat belt use. This is supported by the fact that seat belts are widely used in Denmark by about 90% of all drivers (Færdselssikkerhedskommissionen 2007), while less success can be found regarding loss of weight or smoking cessation (Regeringen 2002).

Also, it is central to the effect whether the reward is given or announced *immediately* or *delayed* in connection with the activity. A delayed feedback results in many cases in a substantially smaller effect (Hattem, Mazureck 2005, Hagenzieker, Bijleveld & Davidse 1997, Luo et al. 2009). Hattem and Mazureck found that feedback shown immediately on a display during the trip had the greatest effect on the participating drivers' driving behaviour (86%). Feedback given when the trip was completed had considerably less effect (27% on a website and 21% on a display in the car). Monthly feedback had the smallest effect on their driving behaviour, 18%.

It is uncertain how the size of incentives influences driving behaviour, but it seems reasonable to assume that the *relative* effect of incentive diminishes with an increased level of incentive, as found by

Litman (2008). It was found that even a small amount of money or the reminder of money in tests has a clear effect on behaviour (Kane et al. 2004, Vohs, Mead & Goode 2008). There are few studies in which the effect is studied in relation to the size of incentive. However, in two ISA trials different sizes of incentive were studied. In one it was found that there might have been a slight connection between the size of incentive and the effect, but it could not be established if this was due to stepwise decreased incentive or to a general reduced effect over time, or both (Hattem, Mazureck 2005). In another trial, a successor to the *Borlänge* ISA trial, no clear effect of the size of incentive was established (Hultkrantz, Lindberg 2009).

It seems that incentive has effect on e.g. driving behaviour while the size of the incentive might be of less importance. More obvious short-term effects than long-term effects can be expected while lasting effects might be limited or non-existing and depend highly on the characteristics of the change in behaviour. Also, feedback given promptly has normally a substantially better effect than if it is given later.

3.2 Two Danish ISA trials

3.2.1 Reflections about a new ISA design

Despite the general effectiveness of ISA and users' approval of the system, there has not, until recently, been a commercial breakthrough for ISA. It seems that more than goodwill is needed before drivers voluntarily invest in ISA. Also, an incentive may be necessary in addition to just information about the current speed limits and warning if speeding occurs to keep the effort of ISA.

In the *INFATI* trial, ISA has shown significant effect and a great potential for reducing speed-related fatalities and injuries. The participants assessed the warning female voice message, which was used, as very efficient and useful. Furthermore, a very convincing reduction in the level of speed was found in this ISA trial (Madsen 2001, Nielsen, Boroch 2001). These informative and warning ISA elements were therefore assessed as a suitable basis for future ISA trials. However, the diminishing effect over time, which was found in some trials, had to be avoided and an *incentive* element of ISA was therefore added to the *recording*, *warning* and *informative* ISA. Thus it was made possible to test the carrot in combination with more traditional ISA functions and to test the effect on the groups of drivers who needed it most.

With the above-mentioned intention of getting motorists to choose the proper speed and on the basis of the experience gained from other ISA trials, particularly from *INFATI*, two new Danish ISA trials were carried out in the period 2004 to 2009. They were almost identical but with different types of drivers as test groups and different levels of incentives. The two trials will be expanded on later.

3.2.2 The ISA system in general

With minor differences, the two Danish ISA trials have used similar ISA equipment. The ISA system consisted of a GPS receiver with a cell phone, which was used for storing a digital speed map on the memory, calculating the actual position of the car, storing FCD and sending and receiving data to and from a server. Data was sent by a General Packet Radio Service (GPRS) unit. To inform the driver, a display with small loudspeakers was connected to the modified cell phone. All those elements made up the *On Board Unit* (OBU). The display was usually mounted in the air nozzle to the right of the steering wheel. Besides showing the current speed limit, the display would also show the number of penalty points incurred during the current trip and the total number of penalty points incurred during the period in question (expanded on below). Based on the GPS position, the OBU would calculate the current position and match it to a road in the speed limit map (*map matching*). Hence, the OBU matched the current speed with the posted speed limit according to the speed limit map, and the driver was provided with feedback. See Figure 3.1.

Feedback to the driver

With the ignition turned on, the OBU was active and so were the map matching, the logging, and the related calculations. All calculation was done in real time. Map matching was done within approximately 35 milliseconds giving the driver immediate feedback if the speed limit was violated. The system always gave information about the current speed limit. If the speed limit was violated by more than 5 km/h, a verbal warning would follow. It was repeated every 6 seconds until the speed was back below the speed limit + 5 km/h. The 5 km/h speed limit violation which activated the ISA was selected because most Danish road users drive close to the speed limit, but not necessarily below it, as indicated in Section 1.3. It was assumed that if an ISA system that reacted as soon as the speed limit was reached was implemented, the participant drivers would have felt pressure too often from the cars driving behind them as also found in other ISA trials (Vlassenroot et al. 2006, Adell, Várhelyi 2008).

The reason for allowing two warnings before giving penalty points was based on the following considerations: on the one hand, the aim was to design a system which did not allow too much speeding, i.e. too long intervals before speeding results in penalty

Figure 3.1. The display with a loudspeaker (left), and the OBU, which was normally mounted under the dashboard (right).

points. This would speak in favour of short intervals between the penalty points. On the other hand, it was also important that the participants were able to overtake for example a truck with a trailer without getting penalty points. According to Danish law, it is not legal to violate the speed limit during overtaking procedures. Actually, that is what frequently happens, and consequently there was some concern that the drivers' fear of getting penalty points when overtaking might constitute an accident risk. That might be an argument in favour of a longer interval between the warnings. However, the solution was to have a short interval between the warnings and in return allow two warnings before penalty points was given. The decision was supported by experiences gained during extensive test trips before the launch of the project. The number of penalty points incurred during the current trip was shown in the bottom right corner of the display, while the sum of all penalty points given in the course of the period in question was shown in the left bottom corner. If the map matching was of poor quality, the best estimate of the current speed limit was shown in brackets in the display. No penalty points would be given in that case. The number of penalty points per warning depended on the severity of the speed violation. The more serious the violation, the larger the number of penalty points. See Table 3.1. The principle of progression corresponds to the one incorporated in the Danish Road Traffic Act. No fine is given if the speed violation is less than 10% of the speed limit + 3 km/h (uncertainty margin).

Data and information flow
The OBU got the position of the car from a GPS receiver. On the basis of that position, map matching was carried out immediately to place the vehicle on the right *road segment* (see below). Based on information from the GPS receiver and from the speed map, the OBU each second calculated a number of *attributes* related to the position such as: position, time, speed, speed limit, road number, and a number of attributes describing the quality of the GPS signal and the map matching. *One second log* (1sec-log) is the technical term for that process. When a driver received penalty points, a list of the relevant attributes would be attached. The data and information flow in the ISA system is illustrated in Figure 3.2.

Table 3.1. The relationship between speed limits, the current speed and penalty per warning.

	Speed violation intervals							
Speed limit (km/h)	Speed limit + 5 km/h	<20%	20% - 30%	30% - 40%	40% - 50%	50% - 60%	60% - 70%	
15	<21 km/h	-	-	-	21-22.5 km/h	22.5-24 km/h	24-25.5 km/h	
30	<36 km/h	-	36-39 km/h	39-42 km/h	42-45 km/h	45-48 km/h	48-51 km/h	
40	<46 km/h	46-48 km/h	48-52 km/h	52-56 km/h	56-60 km/h	60-64 km/h	64-68 km/h	
50	<56 km/h	56-60 km/h	60-65 km/h	65-70 km/h	70-75 km/h	75-80 km/h	80-85 km/h	
60	<66 km/h	66-72 km/h	72-78 km/h	78-84 km/h	84-90 km/h	90-96 km/h	96-102 km/h	
70	<76 km/h	76-84 km/h	84-91 km/h	91-98 km/h	98-105 km/h	105-112 km/h	112-119 km/h	Etc.
80	<86 km/h	86-96 km/h	96-104 km/h	104-112 km/h	112-120 km/h	120-128 km/h	128-136 km/h	
90	<96 km/h	96-108 km/h	108-117 km/h	117-126 km/h	126-135 km/h	135-144 km/h	144-153 km/h	
110	<116 km/h	116-132 km/h	132-143 km/h	143-154 km/h	154-165 km/h	165-176 km/h	176-187 km/h	
130	<136 km/h	136-156 km/h	156-169 km/h	169-182 km/h	182-195 km/h	195-208 km/h	208-221 km/h	
Penalty points per warning	No warnings	1	2	3	4	5	6	

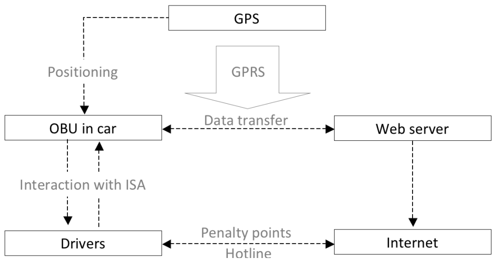
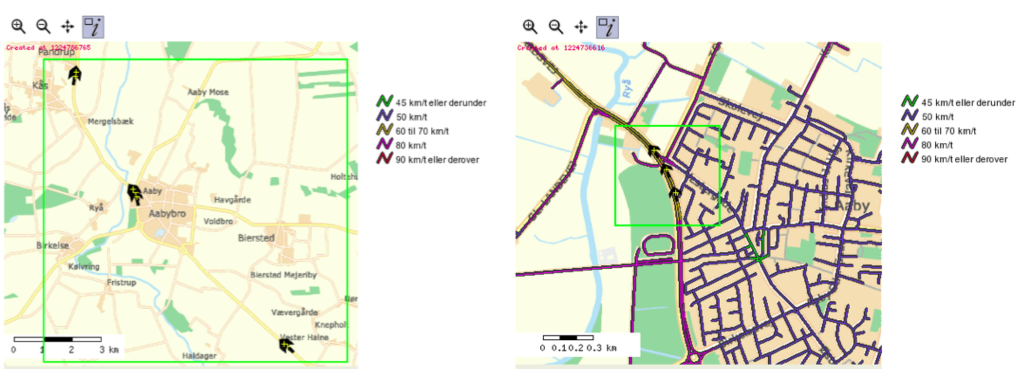


Figure 3.2. Data and information flow in the Danish ISA (Agerholm et al. 2008b).

FCD and penalty-logged data were collected from the driving behaviour. All data were sent to a server via GPRS. The driving log was for research purpose only and was sent during nighttime. The *penalty log* was transferred immediately after the end of the trip during which it was made. The system could also send *error logs*, which might indicate cheating. Immediately after a trip, the driver could access a password-protected personal webpage with information about possible penalty points. The penalty points were shown on an interactive map as well as in a table with information about the speed, the speed limit and the number of penalty points connected with each warning. Warnings, which did not result in penalty points, were not shown on the map. Due to poor GPS reception, wrong map matching or other circumstances, a wrong speed limit could be connected with part of the trips and wrong penalty points could be given. In that case, a hotline could be contacted by email or phone. If the hotline accepted that wrong penalty points had been given, they were removed. Figure 3.3 shows an example of the map from a driver's personal webpage.

The map showing penalty points was scalable in relation to the geographic expanse of the penalty points. That is, a map showing penalty points received at the start or end of a long trip would be small scale while, for example, three penalty points received at six second intervals were shown on a large-scale map. Furthermore, the map was



Hastighedsgrænse	Bilens Hastighed	Antal point	Dato og tid	Overskridelse nr.	Tur nr.
80	87	1	22.08.06 kl. 12:46:56	260	393
80	86	1	22.08.06 kl. 12:47:02	261	393
70	98	4	22.08.06 kl. 12:53:00	262	393

Hastighedsgrænse	Bilens Hastighed	Antal point	Dato og tid	Overskridelse nr.	Tur nr.
70	98	4	22.08.06 kl. 12:53:00	262	393
70	82	1	22.08.06 kl. 12:53:06	263	393
70	78	1	22.08.06 kl. 12:53:12	264	393

Figure 3.3. An example of feedback to a driver in case of penalty points with a small-scale overview (left) and a large-scale overview and visible speed limits (right).

scalable as desired. The speed limits were shown with different legends but were only available when the map was large scale.

Speed Map maintenance
Due to the fact that ISA is highly dependent on an up-dated speed map to give adequate feedback to the drivers, a fast and reliable up-dating of the speed map is crucial. For example, the participating drivers in the *TAC Safecar* trial found that the most serious problem during the trial was inaccurate speed limits (Regan et al. 2006b). Furthermore, both Dutch and English governmental reports have stressed that keeping a speed map updated is a challenge and that it is essential for a successful ISA trial (Gelderen 2005, Jeyes 2005). Hence the Norwegian state and municipalities created a digital road map scheme in 1999. However, after four years, a majority of the municipalities still had not contributed to the database (Akre 2003). A Swedish ISA trial in Stockholm had massive delays as well, which were mainly caused by problems with the digital speed map (Swedish Road Administration et al. 2005). Moreover, commercial providers of digital maps had had some problems keeping their maps updated. With the above-mentioned challenges in mind, the digital speed map for PAYS was devised and implemented, and attempts were made at maintaining it. The subject will be further elaborated on below.

Structure of the speed map
Basically a speed map only needs to consist of a road centre theme and the speed limit as attribute data. However, in a number of places on the Danish road network there is a different speed limit in the two directions. Hence, the digital speed map, which was developed, contained two speed limits, one in each direction, the road centre as coordinates, and a unique road number.

The initial update of the speed map
The lesson learnt from the *INFATI* trial was, that it was not easy to get hold of an updated speed map. Only a minority of the local road authorities, municipalities for example, had available data on their speed limits in a digital form. As regards the national road network, most data were available, although up to a couple of years old, furthermore with a large uncertainty on the quality. With an almost updated road centre theme, but insufficient speed limit data, the existing speed limits had to be collected as part of the PAYS trial.

For a number of reasons, it was decided to collect the speed limit data from the speed limit signs on the road network and subsequently transform the data to speed limits on the road network. For that purpose a customised keyboard was developed, which was connected to a GPS receiver and included a key connected to all road signs of relevance. Then two students spent approximately 8 weeks driving through most of the road network in the County of North Jutland - about 22,000 km - to collect the data[18].

The continuous speed map updating procedure
Basically there are two approaches to updating speed maps. 1: based on feedback from and maintained in co-operation with the road authorities in the area, and 2: by means of mobile mapping, i.e. travelling the road network while collecting data at

fixed intervals, which vary according to the size and importance of the roads.

The first approach was selected in this case because, in theory, it would always result in an updated speed map. A web application, to which the road authorities could transmit updates electronically, was therefore developed and presented to the 27 municipalities in Northern Jutland in 2005.

Feedback from municipalities

In November 2006 the municipalities were contacted by phone to learn how they had used the web application so far. The response was a bit disappointing. Only 46% of the municipalities had worked with the web application at all, and only 38% had made updates. Hence the status was that feedback was given about less than 4,000 km of municipal roads. The reasons for the lack of feedback from the municipalities are shown in Table 3.2.

28% of the public servants in the municipalities, who had not used the web application, stated that they had forgotten about it, 21% had no resources for the task, while only 14% said that poor IT skills were the reason for not using it. The remaining 37% stated that there had been no changes in their speed map since the beginning of 2005. Nevertheless, members of the PAYS project team have registered a number of changes on the road network in these municipalities!

In addition, it was registered how the municipalities stored information regarding speed limits on their road network. In a majority of the municipalities no former registrations were used for checking out the speed limit signs. The administrative officer(s) in charge kept the information in their heads - if necessary with a supplementary visit on location. Most speed limits were originally approved by the local police and ought to be available in a memorandum somewhere. However, the information was not used afterwards and did not act as a record.

A couple of municipalities supplemented that procedure by using the PAYS web application - as initially intended. In most of the large municipalities the information was stored in a database and also in some cases in Geographic Information Systems (GIS). One municipality used a GIS map supplemented with the PAYS application. Consequently, the speed limits for some 53% of the public road network were not stored, and only approximately 23% was available on maps. See Table 3.3.

The lesson learnt was that the speed map update did not work satisfactorily and that

Table 3.2. Reasons for not having used the web application (no. of municipalities).

	No changes	Forgotten	Lack of resources	Poor IT-knowledge
Reasons for not using the webpage	5	4	3	2

[18] The 22,000 km of roads included a number of dirt roads. The public roads consisted of approximately 11,000 km, of which the municipalities were responsible for about 85%.

Table 3.3. The municipalities' procedures for storing their speed map data (responsible for no. of km roads).

	In the mind	In a database	On a GIS map	PAYS-application	PAYS-application + on a GIS map
Registration of signs	4,080	1,118	695	719	1,042

in general the municipalities were far from having a digital speed map. It is obviously practicable to create a speed map, while the real challenge is to keep it updated. After all, the municipalities were undergoing a major reform the outcome of which was fewer and larger municipalities from 2007 onwards. This process, which, three years later, was still very time-consuming in many municipalities, might be part of the explanation to the poor feedback from some municipalities. So the overall experience was that a speed map that did not involve the municipalities might have been kept updated more easily. More details on the speed map are available in Agerholm et al. (2007).

3.2.3 Pay As You Speed

Background

The first ISA trial called Pay As You Speed (PAYS) was planned, carried out and evaluated by Aalborg University in cooperation with the Danish insurance company Topdanmark and the local IT-company M-tec. In addition, the former County of North Jutland and the former Danish Road Safety and Transport Agency contributed towards the trial. The overall purpose of PAYS was to have a test period of three years with 300 young car drivers as participants in the project during which the car insurance rate of the drivers would be related to the amount of speeding.

Young drivers were the desired target group for the following reasons:

- young drivers have an unusually high accident risk in traffic,
- young drivers have been under-represented in many ISA trials,
- In general, the drivers who need ISA the most are less willing to have it (Jamson 2006) - A reason that might explain some of the absence of young drivers in most other ISA trials, and
- in Denmark, young drivers in general pay a considerably higher insurance rate than do older drivers. The yearly insurance rate can be as high as € 2,400 for a novice driver depending on the size and type of car (Lahrmann et al. 2007). The annual rate is rapidly reduced if there have been no damages. However, in spite of the high insurance rate, young drivers put the insurance companies to more expense than the price of the insurance premium they pay. In round figures young drivers will cause expenses, which are 30% higher than the rates paid. Due to the high premiums, a potential reduction of the insurance rate should be extremely valuable to young drivers and for the insurance companies.

Young drivers' high accident risk, high insurance rates, and reluctance to participate in ISA trials formed the basis for the overall hypotheses for the trial: a speed-dependent bonus on the insurance premium would get young car drivers to accept ISA in their car and in addition, such an ISA system would reduce their speeding substantially. PAYS was named after the Pay As You Drive car insurance which is based on the principle that the premium is calculated on vehicle usage, particularly distance driven and time of the trip.

Research design

Initially, the drivers in PAYS had a potential bonus equal to 30% of the insurance rate. In case of speeding, the penalty points would reduce the bonus bit by bit. However, no matter how much a driver had been speeding, he could not incur a negative discount, that is an increased insurance rate was not an option. Each penalty point was worth € 0.07 and the discount was to be calculated for the periods shown in Figure 3.4. Every 6 months, the accounts would be settled on the basis of the driver's driving behaviour during the preceding six months.

The first 1.5 months was a baseline period with ISA deactivated. However, to measure the effect of ISA it was necessary to estimate the participants' *normal* driving behaviour, which was logged. The bonus on the insurance rate was given no matter how the driving behaviour had been during the baseline period. One might argue that the presence of ISA equipment would affect the drivers' behaviour so he/she would be speeding less than usual. This effect cannot be totally neglected, but reasonable this effect is limited. Furthermore, according to another Danish study of driving behaviour, the effect of such equipment is limited[19]. Consequently, it is assumed that though the presence of the ISA equipment might have had a slight effect, it was still limited.

After baseline, the participating drivers were randomly divided into four groups with different ISA treatment for the next 4.5 months - an experimental period. This distribution enabled the effect of different parts of the ISA to be measured. The four ISA conditions appear in Table 3.4.

The *control* group continued like in baseline: no information or warnings and no reduction in the discount. The *incentive* group continued with no real-time feedback. However, penalty points were available on the personal webpage and would result in reduced discount on the insurance rate. The *information* group was given only information and warnings, however,

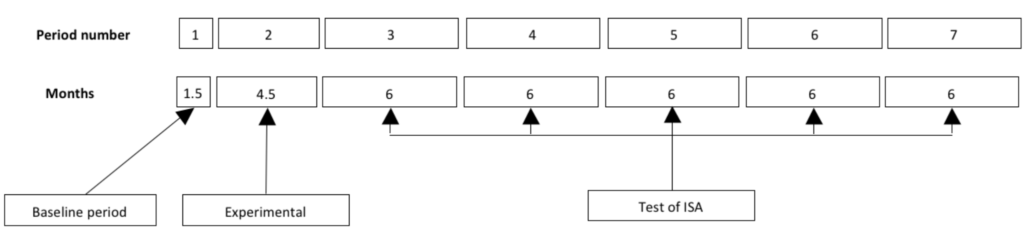


Figure 3.4. The scheduled periods of the PAYS trial.

[19] A recently completed Danish study involving a number of cameras placed in the vehicle to monitor driver behaviour showed that after a period of only two weeks, some of the drivers had picked their nose, done red light driving etc., that indicate limited awareness of monitoring systems (Jørgensen 2008).

Table 3.4. The four different ISA conditions.

		Incentive	
		-	+
Information	-	Control group The participant receives neither information nor warnings or penalty points and continues as during the first 1½ months.	Incentive group The display and the voice message are switched off and no information or warnings are given. Speeding gives penalty points, which the participant can then check on the web.
	+	Information group The display and the voice message are connected and information and warnings are given. Speeding gives no penalty points.	Combination group The participant receives information and warnings and gets penalty points if speeding.

their driving behaviour did not affect the discount. In the *combination* group, the participants received information, warnings, and any reduced discount in case of speeding. The *combination* mode was the main mode for the trial, and after the first 6 months, all participants drove in this mode until the trial was interrupted. These four different treatments are subsequently denoted as *control*, *incentive*, *informative*, and *combination* (Agerholm et al. 2008a).

Besides driving data logging, the participants also received a number of questionnaires. In month 1 (baseline) an attitude questionnaire was sent to all participants. It asked about personal data, attitudes to speeding and traffic behaviour in general, any former accidents, and the pre attitude to ISA. Approximately 4.5 months later, i.e. when the participants were still driving under one of the four different ISA conditions, an almost similar questionnaire was sent out to measure how the different ISA conditions affected the participants' attitudes. After this, a questionnaire concerning any accident involvement was sent out every three months, and finally another attitude questionnaire was sent out to measure any long-term changes in attitudes shortly before the ISA was turned off. All questionnaires were web based and data were transmitted directly to a database for future use. A more thorough introduction to the first two attitude questionnaires is available from Harms et al. (2008).

The plan to involve 300 participants for three years was decided because general accident statistics suggested that this sample size and length of trial period would make it possible to make statistically reliable calculations on the actual number of accidents. Hence, the effect of ISA could be measured directly. However, due to extensive problems of recruitment, it was not possible to reach the target of 300 young participants. During the recruitment campaign, several changes were made in relation to participation terms and recruitment procedures. First of all, the initial age group (18 - 24 years old) was expanded (18 - 28) then removed altogether. Participation fees (approximately € 660) were given up and replaced by a smaller deposit (approximately € 130), which was returned to the participant at the end of the trial. To move the ISA equipment from one car to another (in case of buying another car) was free of charge once due to the fact that many young drivers in the trial change cars quite often. Furthermore, information letters were sent to relevant car owners in the age group several times, and direct marketing was also used. However, in spite of a lot of initiatives, it was not possible to recruit the desired number of participants. Still, it was possible to calculate the effect on the speed changes and subsequently measure the effect by using the Power Model. Furthermore, the cost of transmission related to data transport and map updates turned out to be much higher and also more difficult than expected. Consequently, the project plan was changed according to Figure 3.5.

The recruitment lasted for approximately 20 months in all. The first participants got ISA installed in their cars in May 2006 while the last got the equipment in January 2008. A total of 153 vehicles taking part in PAYS there was wide variation in the position of the participants during the project period. One common date was decided on for the termination of the trial. In addition, it was decided to implement a 'post period' with ISA deactivated to allow any remaining effect of ISA to be measured. Consequently, some participants got an almost full three-year trial while others only got part of period 3. The last OBU was uninstalled in January 2009.

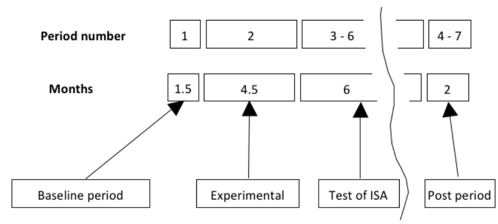


Figure 3.5. The revised plan for PAYS.

3.2.4 ISA Commercial

Background

ISA Commercial (ISA C) was planned, carried out and evaluated by Aalborg University in cooperation with the former Municipality of Børkop, now the Municipality of Vejle, and the IT company M-tec.

Not only young drivers, but also other groups of road users, such as drivers of commercial cars, are overrepresented in road accident statistics. Commercial drivers have a bad reputation among other road users due to their speed behaviour. In Denmark, the road accident statistics show that they are approximately 125% more likely to be part of accidents with fatalities or seriously injured persons than are passenger cars (Brems, Munch 2008). Consequently, commercial drivers were the target group in the ISA C trial.

In addition to the PAYS system a system to record who the driver was, was implemented in ISA C. Due to the fact that commercial vehicles might have a number of responsible drivers, it would not be fair to blame one driver for other drivers' speeding. Consequently, a key reader was installed on the display and each participating driver was given a personal key, which had to briefly touch a contact on the display before a trip was initiated. If a driver

Table 3.5. Participating cars and drivers in the six companies.

	No. of participating vehicles	No. of participating drivers
Small company	5	5
Small company	5	5
Small company	5	5
Small company	1	1
Local road authorities	5	7
Large company (post office)	5	28
Total	26	51

forgot to use the key, a female voice would remind him/her every tenth second up to 10 times. The system was developed so it did not ask for key ID until 10 minutes had passed since the previous reminder.

ISA C involved 26 commercial cars and 51 drivers in total for approximately one year. The cars were distributed among six companies. The drivers coming from the four small companies were service engineers, workmen etc. The drivers recruited from the local road authorities were a mix of road workers and administrative staff while in the last company, the local post office, they were postmen (see Table 3.5).

Research design
ISA was installed in the period March to June 2007 depending on the availability of the company fleet vehicles. The first approximately two months was set as a baseline like in the case of PAYS. After the activation of ISA, the behaviour of each driver was calculated monthly. The periods of ISA C are shown in Figure 3.6. Once a month the driving behaviour was calculated on the basis of two parameters: the number of *penalty points* and the *distance driven*. The number of penalty points per distance driven was calculated for each driver and those of the drivers who had driven more than 500 km per month would compete to be *driver of the month*. The required amount of 500 km per month was set because it was not considered fair to allow a driver travelling short distances the opportunity to win - all things being equal, it is easier to observe the speed limit on a few trips than it is in case of a daily driving need.

The results were calculated on a monthly basis for each driver and for each company. Company results included all driving, also driving without use of the personal key. The results could be found on a webpage, which included:

- a table with the overall results and the name of the driver of the month,
- a table on a webpage with restricted access, displaying the results for each driver and on which the drivers could see each colleague's results while the results of the other drivers were anonymous.

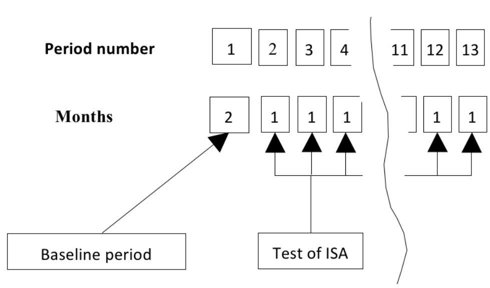


Figure 3.6. The scheduled periods of *ISA C*.

The reward was a shopping basket worth some € 40. Also the overall best drivers were found. When the trial stopped, the ten drivers with virtually no penalty points and sufficient registered driving on their personal key received a GPS navigator for their private car as a reward. The rewards, monthly and final, and especially the social control due to the information on the webpages were intended as incentives supplementary to the informative and warning aspects of ISA. It was assessed (but not studied) among the research project team that the social control had more effect than the incentive.

The recruitment of drivers was carried out indirectly and each company decided participation. The individual driver did not decide the matter, so some of the drivers were not volunteers. However, each company seemed to have different approaches when it came to selling the idea to the drivers. That aspect was not studied specifically, but during the evaluation of questionnaires and the monitoring of key use, it became clear that the attitude to the trial varied considerably from company to company.

In ISA C too, a couple of questionnaires were sent out. They were almost identical to the two first attitude questionnaires in PAYS, but where necessary they had been divided into questions concerning the use of the private car and the use of the commercial car (Agerholm, Tradisauskas & Lahrmann 2009).

3.3 Objective and limitations

Many ISA trials have shown significant effect on the participating drivers' driving behaviour. Most participants found ISA positive, but unfortunately only a few of the most exposed road users like young drivers participated in these trials. Also, incentive might affect driving behaviour in the desired direction more than it is possible with e.g. information and warnings alone. Two Danish ISA trials were carried out to test if ISA combined with various types of incentives could reduce speeding among the participating drivers. Also it was expected that a decreasing effect of ISA over time could be avoided if an incentive was connected with avoidance of speeding. It was the hypothesis that an incentive to avoid speeding connected with ISA feedback would result in a higher and more lasting effect of ISA than could otherwise be expected. Another hypothesis was that the effect of incentive without ISA feedback would have a more lasting effect than ISA feedback without an incentive.

ISA C and PAYS in particular are major trials with many subjects to be taken into account. In this thesis it was therefore decided to focus on short and medium-term effects of ISA on exposed road users only. Long-term effects as well as results in all age groups of participants are reported elsewhere, and so are more technical issues as well as studies concerning attitudes among the participants. This division of research areas also reflected the positions and professional skills among the researchers in the research group behind the two ISA trials, so professional skills were merged as well as possible with the different areas of research.

In the light of the hypotheses regarding ISA and incentive and the composition of the research group it was reasonable to ask the following question in order to increase knowledge about the effect of informative and warning ISA combined with incentive:

How are exposed groups of drivers' driving behaviour influenced in the short and medium-term by informative and warning ISA together, incentive ISA, and a combination of these in correlation with incentives of various size and type?

The focus being on exposed road users, young drivers and commercial drivers were selected. They were the initial target groups in the two ISA trials. Information, warnings, and a combination of these in correlation with incentives made up the ISA treatment in the two trials. Short term is here defined as approximately 0 to 2 months after activation of ISA, while medium term is defined as approximately 3 to 6 months after activation of ISA. The results will be based on the FCD collected in the PAYS and ISA C trials.

Research regarding short and medium-term results was selected because after 4.5 months with ISA activated in PAYS all participating drivers started to drive in the *combination* mode. Hence, benchmarking between the effect of incentive, information and the combination of these was not possible after that time. Furthermore, for ISA C a substantial proportion of the participating vehicles did not drive with ISA during the whole trial period due to erroneous OBUs and earlier dismantling than planned. Hence, benchmarking of long-term effects is not possible with the data available, although the results are central, and measuring of medium-term effects is assessed as giving the most reliable estimate of the effect of e.g. a UBI scheme with regulations similar to the ones presented regarding PAYS.

4 Methods

4.1 Data

4.1.1 Data selection and treatment

Several types of data can be used to measure changes in driving behaviour. If the penetration rate of a measure is sufficiently high it might affect the general traffic pattern. Therefore it is not the absolute effect on the individual driver that should be measured, but preferably the general change in traffic pattern. That was the case in the ISA trial in *Umeå*, where the mean speed was reduced, probably due to ISA (Biding, Lind 2002). Since PAYS and ISA C only included FCD from 153 and 26 cars, respectively, the effect of ISA would not be measurable by standard traffic data such as mean speed on road sections or general accident statistics. Thus it is necessary to measure the direct effect of ISA on driving behaviour[20].

As in most ISA trials the effect was measured by data logging of driving behaviour. In principle, data logging works as an observational study, but with the logging as a passive observer. Hence any act can be measured while any explanation for an act is unavailable (Andersen et al. 2002). Moreover, the results found are objective - no interpretation bias can occur on the basis of raw FCD, and in theory, data logging will register driver behaviour exactly as it was. The fact is that even though the FCD are precise, still minor parts of the registrations are inaccurate. In the two Danish ISA projects approximately 5% of the observations were left out due to these errors (Tradisauskas et al. 2009). However, nothing indicates that these errors and the subsequently omitted erroneous data caused biased results, and FCD is therefore selected as the source for analysis of the effect of ISA on driving behaviour.

The FCD were collected with 1 Hz and were stored in an *Oracle SQL* database. As it will be expanded on below, all analyses are based on the *distance driven*, not the *time driven*. Basically all FCD are prepared for measuring the distance driven under different speed limits, different ISA conditions, and different time periods. To achieve sufficient FCD quality and facilitate statistical tests, the FCD have been divided into the following subgroups:

- grouped by each ISA treatment (four in PAYS and one in ISA C),
- grouped by each speed limit (50, 80, 110, and 130 km/h),
- grouped by each speed (0, 1 …, 200 km/h), and
- grouped by each period (e.g. baseline, ISA 1, ISA 2, ISA 3).

FCD distributed on treatments makes it possible to analyse differences in driving behaviour and changes in driving behaviour due to different ISA treatments. The data for driving behaviour on roads with different speed limits is essential for the differentiation between the effects of ISA on different road types - a difference that was very significant in most ISA trials.

[20] Accident registrations among the participating drivers can provide the exact estimate of the effect on road safety due to ISA. However, it requires a markedly bigger number of participating drivers than there were in the Danish ISA trials because the average driver has to drive in several hundred years before he will be involved in an police reported accident with serious injured persons (Statistics Denmark 2010, Nilsson 2004).

Grouping FCD by speed serves to measure all effects regarding behaviour such as the proportion of the distance driven above the speed limit + 5 km/h. Additionally, grouping FCD facilitates the transformation of data from the time driven to the distance driven at a selected speed. The equation for these calculations is:

$$Dist = \sum \frac{\sec \cdot speed}{3{,}600}$$, where

Dist is the distance driven in km,
sec is the number of seconds driven at a given speed,
speed is the actual speed in km/h , and
the value 3,600 in the denominator converts m/s into km/h.

The subsequent analyses of driving behaviour are all carried out in spread sheets. Further explanations regarding the selected measurements are expanded on when necessary in connection with the measurement in question.

4.1.2 FCD selection

To reduce the number of results and to focus on results regarding the majority of the distance driven, only data from driving on the four following road types are analysed:

- *50 km roads.* 50 km/h is the normal speed limit in built-up areas.
- *80 km roads.* 80 km/h is the normal speed limit outside built-up areas.
- *110 km roads.* 110 km/h is the lowest normal speed limit on motorways.
- *130 km roads.* 130 km/h is the normal speed limit on motorways in less trafficked areas.

All roads with a speed limit below 50 km/h were removed from the analyses, because in most cases road segments with these speed limits are equipped with speed calming road design, e.g. speed humps, rumple strips, and chicanes. Also, other road types with higher speed limits have a low proportion of the distance driven and are therefore removed from the analyses. Despite the low number of road types the included FCD contains 84% to 91% of the total driving included in these analyses regarding PAYS and ISA C, respectively. FCD from all vehicles involved in the ISA C trial are included here. The total amount of FCD included in this study consists of 66 million observations.

4.1.3 Research design

The purpose of this thesis is to evaluate the effect of ISA combined with incentive in the short and medium term. Even though the same ISA principle and the same ideas regarding the overall research design in the two trials were carried out, they are quite different, and only few and very general comparisons between results from the two trials are made.

In PAYS the baseline of 1.5 months was followed by a 4.5 month experimental period, during which the drivers were distributed randomly to four different types of feedback regarding the ISA system. The purpose being to measure any effect of incentive and information over time, it was reasonable to focus on the latter period instead of the period with fully implemented ISA during which it is not possible to distinguish between e.g. the effects of *incentive* vs. the effect of *information* and *warnings*. Consequently, the baseline driving behaviour is compared with driving behaviour in the three 1.5 month periods of the experimental period. Regarding ISA C the research design was simpler. A baseline period of approximately 2 months was followed by 1 year of driving with ISA activated. To reach the set target, the driving behaviour in the baseline period is therefore compared with the effect of ISA in the subsequent three periods of 2 months each. For both trials these three periods after the baseline period are denoted *ISA1*, *ISA2*, and *ISA3*. These periods did not result in completely identical conditions for the two trials, and results from the two trials are only compared in few occasions subsequently.

To measure the effect of ISA on the most risk-exposed drivers all drivers in ISA C and all drivers younger than 29 years old when joining the PAYS trial are included in these studies. This age limit is partly arbitrary, but is based on the facts that 1: it was the new highest age limit used in the recruitment campaign for PAYS, while it still seemed reasonable to get sufficiently many young drivers involved in the trial, and 2: it is a balance between having sufficient participants to get reliable data and focusing on the most risk-exposed drivers, who are the youngest.

4.1.4 Deviations from the research design

A number of OBUs suffered from technical problems, and the number increased somewhat over time. Some of them stopped giving feedback to the drivers, while other stopped collecting data for research purposes. It is assessed as having little effect on results in this thesis, due to the fact that only short and medium-term effects are studied when virtually all OBUs still functioned well. Also, nothing indicates that it will bias any results based on driving behaviour as long as focus is on speeding and not on the distance driven in specific periods. A number of participating drivers stopped prematurely, most of them because they sold their car or moved to another region of Denmark. A few, however, decided to quit because they disliked driving with the PAYS equipment.

It seems plausible that these drivers were more keen on speeding than were the remaining participants. So if the former had continued participation, the results would probably have been more significant because they were the ones speeding the most and would therefore have been most affected by ISA. Had they had a negative attitude to ISA in advance, they would probably never have participated in the trial. Consequently, it is assessed that any lack of data due to technical problems or premature exit from the project have minor effect on the results.

4.2 Time driven vs. distance driven calculations

4.2.1 General problems with the *time driven* approach

Various methods have been used for estimating the effect of ISA in various trials. Some results are based on the *time driven* while others are based on the *distance driven*. Results are diverse and it seems that results from trials where results were estimated on the basis of the *time driven* data are markedly smaller than those based on the *distance driven*. However, that might be caused by a number of other reasons such as generally different traffic behaviour in different countries, different sorts of ISA systems, and different attitudes to speeding among the drivers. How these differences might affect ISA results is unknown and it is therefore useful to compare results estimated by the *time driven* and the *distance driven*, respectively.

Research on subjects involving speed, there are basically two approaches: a *time driven* and a *distance driven* one used in most cases. When measuring a single reaction it might often be useful to adopt a time driven approach in dealing with the incident because most road users use the time to a certain subject to assess the most suitable reaction then (Triggs, Harris 1982). It is also the type of approach used in conflict study techniques (Williams 1981). However, if studying speeding in relation to ISA, the use of time above a certain speed as measure can result in a systematic bias. A hypothetical example of that follows below.

$d = s \cdot t$ where,

d = distance,
s = speed and
t = time

then follows:

$d = s \cdot t \Leftrightarrow \frac{d}{s} = t$ and if $s \rightarrow \infty s \Rightarrow t \rightarrow 0$

As a result, the transportation time on a certain distance will decrease and hence a more serious speed violation will be measured as less serious. So, in theory, if a vehicle drives excessively fast, no time will be spent on the road and it will be a completely safe trip. The problem can be illustrated with a practical example:

A car is driving a distance of 1 kilometre on a 60 km road. The vehicle speed without ISA is 75 km/h whereas it is 66 km/h with ISA activated. If using the equation above it will look like this:

Without ISA vs. With ISA:

$$\frac{1.0km}{75km/h} = 48\sec onds \rightarrow \frac{1.0km}{66km/h} = 55\sec onds$$

When the speed is reduced by 9 km/h due to ISA, the time of speeding will increase by 7 seconds. Hence, the reduction of the larger speed limit violation will be measured as an extended period of speeding (from 48 to 55 seconds) if only looking at the time driven above the speed limit.

4.2.2 Speed distribution

To avoid any unknown bias caused by local conditions, FCD from two ISA trials are studied regarding results based on the *time driven* and the *distance driven* approaches. By distributing FCD on speeds any overestimation of e.g. low speeds can be recognized. Also differences in the distribution become distinct. FCD from the *TAC Safecar* and the *ISA C* trials regarding 80 km roads with ISA activated are used for this study. Data from the two trials were selected, partly because they were available, but also because the trials are fairly new, included the same type of driving (commercial vehicles), and in-

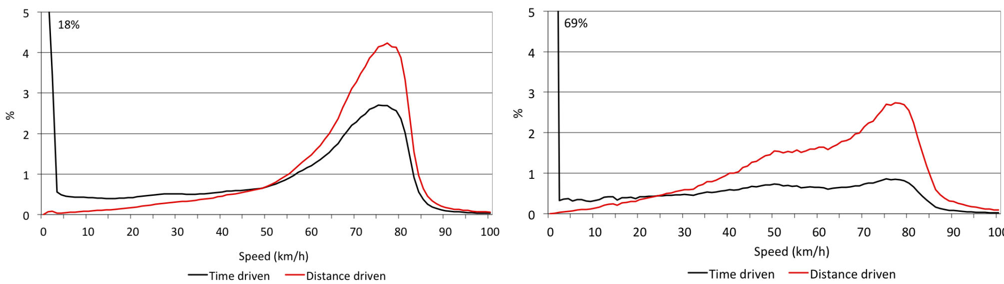


Figure 4.1. The proportion of time and distance driven on 80 km roads in the two ISA trials. Left: distributed on speeds for the *TAC Safecar* trial. Right: distributed on speeds for the *ISA C* trial. Note that the time driven approach results in major fluctuation regarding 0-2 km/h (18 and 69% of the total time driven, respectively).

cluded almost the same amount of transportation[21]. See Figure 4.1.

In both data sets it appears that low speeds are considerably overestimated when measured by the time driven approach. It is particularly significant in the case of the *ISA C* trial. The reason for this difference is probably another use of the cars than in the *TAC Safecar* trial (workmen vs. salesmen). However, regardless of the different groups of users the low speeds are extensive and hence any effect of ISA will be underestimated. This underestimation is especially caused by very low speeds originating from idling, red light stops, and congestions, which by no means can be affected by ISA.

It could be argued that removing the lowest speeds would solve the problem. It will undoubtedly solve the bias caused by idling etc. However, the *time driven* approach will still cause a bias because effects from the low speed will be overestimated. By removing say all speeds <5 km/h the bias will be minimised but not eliminated.

4.2.3 PDA and PTA

Also a comparison of PDA and PTA results for various road types can indicate the differences between the two approaches. FCD from the *TAC Safecar* and the *ISA C* trials distributed on speed limits are used to compare them[22] (see Tables 4.1 and 4.2). The results in each of the two tables are based on exactly the same method, though estimated on the basis of the *distance driven* and the *time driven* approaches, respectively.

[21] In the *TAC Safecar* trial each driver drove 16,500 km. 3,000 km of this distance was driven under baseline conditions without ISA activated while other 3,000 km were driven with ISA activated. With 15 drivers under ISA conditions the total number was 90,000 km deducted any erroneous data. The remaining 10,500 km driving per driver was used for other tests than ISA only. (Regan et al. 2006a). *ISA C* FCD from the baseline period are here compared with FCD from the following 1.5 months with ISA, hence referred to as the *ISA period*. During these two periods the participating vehicles drove 88,000 km in total (Agerholm et al. 2008b).
[22] Violation of the speed limit by 2 and 5 km/h was the threshold for activation of warning ISA in the TAC Safecar trial and in the ISA C trial, respectively. Hence these values are used for the estimations.

Table 4.1. The PDA and PTA+2 km/h in the *TAC Safecar* trial.

	Speed limit									
	50		60		70		80		100	
Approach	PDA	PTA	PDA	PTA	PDA	PTA	PDA	PTA	PDA	PTA
Baseline	24.3	10.4	18.2	8.9	12.1	6.3	10.3	5.6	8.8	6.7
ISA	18.2	8.3	10.3	5.0	8.9	4.6	5.8	3.2	6.2	4.6
p-value	0.1450	0.5621	0.0014	0.0025	0.0038	0.0132	0.0157	0.0403	0.0893	0.1068

Table 4.2. The PDA and PTA+5 km/h in the *ISA C* trial.

	Speed limit									
	50		70		80		110		130	
Approach	PDA	PTA	PDA	PTA	PDA	PTA	PDA	PTA	PDA	PTA
Baseline	18.7	4.4	15.2	6.9	18.9	5.0	25.5	15.7	5.0	3.7
ISA	7.4	0.7	5.1	2.3	4.7	1.2	6.6	4.5	1.3	1.0
p-value	0.0000	0.0000	0.0003	0.0000	0.0000	0.0003	0.0163	0.0106	0.2899	0.2876

When comparing the results based on the *distance driven* with the ones based on the *time driven*, it is evident that the former show lower p-values than the latter. However, it only results in a single case of changed level of significance: in the *TAC Safecar* results on 100 km roads a *distance driven* approach shows a tendency towards statistical significance, while no significance is found in the time driven approach. The decreased difference, which is a consequence of a higher speed limit, may be due to the fact that the amount of idling and driving in congestions will tend to be less when the speed limit is higher. Hence, in the case of roads with high speed limits the two approaches would be most easily compared with each other, but it is here that a different level of significance is observed. Consequently, the values in Table 4.1, and partly in 4.2, indicate that the *distance driven* approach gives more clear results than the *time driven* approach.

4.2.4 Selection of the distance driven approach

On the basis of the studies above it was decided to use the *distance driven* data for further analyses of change in driving behaviour due to ISA. Three reasons seem to speak in favour of the *distance driven* approach: 1: in adopting a *distance driven* approach any bias due to e.g. low speeds and idling is avoided. 2: in deselecting the *distance driven* approach some of the results which should have been treated as statistically significant would not be. 3: also, the *distance driven* is the normal measure of exposure to on-the-road risk (Elvik et al. 2009, Brems, Munch 2008).

4.3 Methods used

4.3.1 Selected methods of measurement

Two main factors of driving behaviour contributing to changed road safety are driving speed and speed variation. Hence, to measure the effects of *incentive* and *informative* ISA on driving behaviour and road safety, three direct measures are selected. The proportion of the distance driven above the speed limit + 5 km/h (afterwards denoted as *PDA* only regarding the Danish ISA trials) is selected because the ISA system gave warnings and distributed penalty points if the speed limit was violated by more than 5 km/h. MFFS is used as a model to estimate the effect of ISA when other road users do not affect the driver - it is reasonable to expect the full effect of ISA under these conditions. Free Flow Standard Deviation (FFSD) is selected because the speed variation affects road safety considerably.

4.3.2 Proportion of the distance driven above the speed limit + 5 km/h

PDA in baseline and in periods with ISA in different modes activated are compared. This way of measuring the effect of ISA was used in several other trials with different levels of speeding from 0 to 20 km/h included. In the *Ghent*, the *ISA UK*, and some of the Swedish large-scale trials, the PDA was measured (speed limit+0, 0, and 2 km/h, respectively) (Vlassenroot et al. 2006, Carsten et al. 2008, Biding, Lind 2002). In the *Karmøy* trial, the PDA (speed limit+5 and 20 km/h, respectively) was measured.

4.3.3 Mean Free Flow Speed

One of the methods to estimate the effect of ISA, which are used in other ISA trials is the so-called *Free Flow Speed* (FFS) or *Free Speed* which, according to the *Highway Capacity Manual*, can be defined as *The theoretical speed of traffic, in kilometres per hour, when the density is zero* (Transportation Research Board 2000). FFS is used with the intention of measuring only the effect of ISA, avoiding any dilution of results due to tail-back driving, congestions, short-time parking, and idling. However, it is difficult to determine which speeds to include when working with FCD. Many researchers have been contacted through the mailing list of the International Working Group on Speed Control (IWGOSC) regarding a definition of FFS when using FCD based on GPS. IWGOSC is an international network working with ISA and related subjects. One researcher has defined Free Flow (FF) as all speeds above 15 km/h while others suggest that it is all speeds above 50 km/h on motorways. In the *TAC Safecar* Project, it was defined as FFS if there were more than 3 seconds between one vehicle and the vehicle in front. A fourth suggestion was to exclude all driving during peak hours. In general, all the abovementioned methods are very static or not an option due to technical limitations such as the car having no FDW installed. Furthermore, leaving out all distances driven during rush hours might reduce the FCD amount and provide less reliable results. It should also be taken into account that a big proportion of the *distance driven* in the two Danish trials took place outside built-up areas, where rush-hour traffic hardly affects speed.

In the two Danish ISA trials, MFFS was defined as it appears in Table 4.3: the speed limit deducted a value. On 50 and 80 km roads, it is the speed limit minus 15 km/h; on 110 km motorways it is minus 20 km/h and on 130 km motorways it is minus 30 km/h. For roads with a 50 km/h speed limit, for example, all distance driven at more than 35 km/h is included. It was assessed that only a few drivers drive more slowly than that, unless their driving behaviour is affected by

Table 4.3. Speeds included in calculations of MFFS in the two Danish ISA trials.

	Speed limit			
	50 km/h	80 km/h	110 km/h	130 km/h
MFFS	>35 km/h	>65 km/h	>90 km/h	>100 km/h

other conditions, which might make them select a lower speed. The limits chosen are based on the PAYS research group's own experiences in the present area of research.

The reliability of the selected MFFS definition was tested by comparing MFFS found in an equivalent way, but based on *TAC Safecar* FCD[23], and results based on driving at a distance of more than 3 seconds from the car in front. The latter were based on FDW data, also from the *TAC Safecar* trial (Regan et al. 2006b). See Table 4.4.

On 50 km roads, the method based on FDW showed approximately 2.5 km/h lower speed than did the PAYS method. The differences between baseline and ISA results are almost identical with the two methods. The lower speed found for the FDW method might be due to other distracting objects on the road - quite plausible on roads in built-up areas. On 80 km roads, the baseline speed was identical for the two methods while it differed slightly when ISA was activated. There are no obvious reasons for this difference. However, on the basis of these considerations it seems reasonable to assume that the selected way of finding MFFS is close to the real MFFS[24] and that it reflects the effect of ISA far more precise than e.g. the mean speed.

4.3.4 Free Flow Standard Deviation

Research has shown that the amount of speed variation influences the accident rate. The more variation in speed, the higher accident risk (Salusjärvi 1981, Finch et al. 1994). Less speed variation therefore indicates that the ISA equipment might reduce the number of accidents more than is achieved through a reduction in speeding only. Consequently, the change in Free Flow Standard Deviation (FFSD) is used as a measure for the effect of ISA. Only driving above a speed limit dependent level is included in the analyses and the levels are the same as regarding MFFS. See Table 4.5.

Table 4.4. MFFS found as a result of removing low speeds and found on the basis of FDW.

	Speed limit				
	50 km/h			80 km/h	
	MFFS for *TAC Safecar* with the proposed approach	MFFS for *TAC Safecar* based on FDW		MFFS for *TAC Safecar* with the proposed approach	MFFS for *TAC Safecar* based on FDW
Baseline	48.5 km/h	45.9 km/h		75.9 km/h	75.9 km/h
ISA	47.7 km/h	45.2 km/h		75.2 km/h	74.6 km/h
Difference	0.9 km/h	0.7 km/h		0.7	1.4

[23] The FCD were from driving under ISA condition, but without FDW activated.

[24] It is reasonable that e.g. the speed limit deducted 10 or 20 km/h on 50 km roads would result in considerable higher deviations compared to the FDW than the selected deduction of 15 km/h.

Table 4.5. Included FCD used for calculating FFSD for the four selected speed limits.

	Speed limit			
	50 km/h	80 km/h	110 km/h	130 km/h
FFSD	>35 km/h	>65 km/h	>90 km/h	>100 km/h

4.3.5 Statistical tests

To estimate any effect on driving behaviour on the basis of driving behaviour in more than one vehicle, there are basically two approaches: the *individual approach* and the *system approach*. With an *individual approach* it is assumed that each vehicle/driver contributes equally to the results, regardless of how much this particular individual contributes to the overall driving behaviour. With a *system approach* the amount of contribution from each driver depending for example on the distance driven is aggregated and the total distance driven is used to measure any effect. Due to the fact that the distance driven being a key measure of traffic safety risk (Elvik et al. 2009), the *system approach* based on the distance driven has been selected for the estimations of the ISA-related effects on driving behaviour in the Danish ISA trials.

The values used for the statistical tests regarding the effect of ISA are the distance driven (km) at the chosen speed compared to the speed limit under different conditions. Regardless of the test type applied, a p-value below 0.05 is considered statistically significant, while a p-value of 0.05-0.10 is regarded as tending to be statistically significant. The data were analysed for each defined road type. In order to document the effects of ISA in PAYS, two-dimensional statistical tests were carried out: 1: across different periods (baseline and three subsequent periods (*ISA1*, *ISA2*, and *ISA3*) for each ISA treatment, and 2: across ISA treatments in each individual period. Due to a much simpler research design in ISA C only tests across different periods were made concerning results per speed limit.

In the statistical analysis of PDA, the *Chi*^{2} test is applied. This test is used because it is not based on the assumption that data are normally distributed (Kreiner 1999). Moreover, even though it is a generic test, which might be less informative than more sophisticated statistical significance tests, still a large amount of data result in diminishing variations between results from a *Chi*^{2} test and from more advanced tests (Kreiner 1999). The MFFS was tested for statistically significant differences by means of the *Wilcoxon Rank-Sum test*. This test was selected because it was found suitable for this data type and for yielding reliable test results, whether the data are normally distributed or not. (Walpole et al. 2007). To test if there are statistically significant differences between FFSD in each period and between each different treatment in the same period a *Levene's tests of homogeneity of variance* is applied. The test was used because the SD has to be compared; SD being the square root of the variance. A *paired t-test* was used to test the differences between a *time driven* and a *distance driven* approach. The analysis was performed in order to determine which type of data is best suited for estimating the effects of ISA. Regarding PDA and PTA in the two ISA trials, *TAC Safecar* and *ISA C*, this test type was used.

A paired t-test was used on an individual level because the purpose was to test data rather than to measure effects of ISA. A t-test is useful in estimating the statistically significant differences between mean values (Kreiner 1999).

Due to the fact that the numbers of data in the statistical tests regarding driving behaviour data in the Danish ISA trials are considerable, it has in general not been a problem to reach results of statistical significance - rather the opposite. Some might argue that all results that are statistically significant should be presented and discussed in detail. However, in this case the discussion has been limited to and focussed upon the most interesting and significant results. More information about the selected statistical tests is available in appendix 2.

4.4 Summary

Due to the small proportions of participating cars compared to all vehicles in the test area any effect of ISA will not be measurable from standard traffic data. It is therefore necessary to identify changed driving behaviour for the individual driver or vehicle. The aim of this report being to study changes in driver behaviour due to incentive and informative ISA, it was assessed that the most reliable results can be obtained from FCD.

Only results based on FCD from the four most used road types are included in this report. The road types included are these: 50 km roads, 80 km roads, 110 km roads, and 130 km roads. The included amount of FCD consists of 66 million observations, which are stored in an Oracle SQL database. They are extracted from the database and grouped by each treatment, each speed limit, each speed, and each period. Afterwards these data are analysed in spread sheets.

Only short-term and medium-term effects of ISA are studied here. Also, only effects on exposed road users are found. By exposed road users are meant the drivers in commercial vehicles in ISA C and all participants younger than 29 years old in PAYS. The effect of ISA will be documented by the following measures: PDA, FFSD, and MFFS.

The tests of statistical significance used in this study are a *Chi*^{2} test for PDA, the *Wilcoxon Rank-Sum* test regarding MFFS, and the *Levene's test for homogeneity of variance* regarding FFSD. Also, a *paired t-test* has been used regarding the considerations about the *time* vs. the *distance driven* approach. It was found that *distance driven* approach results in more reliable results concerning ISA than does a *time driven* approach.

5 Driving behaviour results

5.1 Sample size

The FCD included in the subsequent analyses are based on driving done by the participating vehicles in the two Danish trials. However, some vehicles did not collect data as planned, while in other cases drivers did not meet age requirements for the analyses in this report. Furthermore, some of the vehicles did not yield FCD from all road types simply because the drivers did not drive on these road types. For an overview of the number of drivers included in each period for each road type, see Table 5.1. In total 50 drivers in PAYS met age requirements. However, due to too few data in the periods studied, only data from 44 drivers were included in further analyses. The 44 drivers were distributed over the four categories as follows: 10, 13, 10, and 11 for the *control*, *incentive*, *informative*, and the *combination*, respectively. All drivers had driven on 80 km roads, almost all had driven on 50 km roads, while the proportion was lower regarding 110 km roads and 130 km roads in particular. ISA C, including data from 25 vehicles out of a total of 26, shows a similar pattern. Data included about the distance driven appear in Table 5.2.

Table 5.1. The number of vehicles included in the analyses.

Speed limit	Period	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
	Baseline	10	13	10	11	23
	ISA1	9	13	10	11	24
	ISA2	10	13	10	11	23
50 km/h	ISA3	9	13	10	10	24
	Baseline	10	13	10	11	25
	ISA1	10	13	10	11	25
	ISA2	10	13	10	11	25
80 km/h	ISA3	10	13	10	10	25
	Baseline	8	12	8	9	18
	ISA1	9	11	10	10	16
	ISA2	10	11	9	9	19
110 km/h	ISA3	9	12	9	8	18
	Baseline	8	10	8	9	11
	ISA1	8	10	8	10	10
	ISA2	6	11	7	9	10
130 km/h	ISA3	7	10	9	8	12

Table 5.2. The distance driven distributed over trial, period and road type included in the study (km).

PAYS					
	Baseline	ISA1	ISA2	ISA3	Total
50 km roads	12,720	14,409	14,566	13,291	54,987
80 km roads	37,538	39,910	38,467	34,125	150,041
110 km roads	11,131	11,388	10,012	7,599	40,130
130 km roads	11,393	12,109	12,581	9,603	45,685
Total	72,782	77,816	75,626	64,618	290,843
ISA C					
	Baseline	ISA1	ISA2	ISA3	Total
50 km roads	16,408	15,332	13,714	17,910	63,363
80 km roads	31,285	28,307	25,680	36,689	121,962
110 km roads	3,132	4,050	2,950	5,105	15,236
130 km roads	2,380	2,373	1,943	2,731	9,427
Total	53,205	50,062	44,287	62,434	209,988

Driving on 50 and 80 km roads constituted 70% and 88% of the total distance driven in PAYS and ISA C, respectively, included in this study (50, 80, 110, and 130 km roads).

5.2 PDA

5.2.1 Results

In Table 5.3 appears PDA for all driving included. *Control* had a PDA of 0.21, 0.22, 0.24, and 0.27 regarding baseline and the three ISA periods, respectively. Baseline-ISA1 and ISA1-ISA2 were statistically significantly different (p=0.02). All other changes were statistically significant (p=0.00). *Incentive* had a PDA of 0.14 in baseline and of 0.04 in the three ISA periods, respectively. All changes between baseline and ISA were statistically significant (p=0.00), while differences between the ISA periods were not. *Informative* had a PDA of 0.14 in baseline and 0.08, 0.09, and 0.10 in the ISA periods, respectively. Changes between baseline and ISA were statistically significant (p=0.00), while the difference between ISA1 and ISA2 (ISA1-ISA2 etc.) and ISA2-ISA3 were statistically significantly different (p=0.01). *Combination* had a PDA of 0.20, 0.05, 0.02, and 0.02 for baseline and the three ISA periods, respectively. ISA2-ISA3 were statistically different (p=0.01) and the remaining differences were statistically significant (p=0.00). Regarding *ISA C* PDA was 0.17, 0.08, 0.07, and 0.10 for baseline and the three ISA periods, respectively. All differences were statistically significant (p=0.00). The differences between the different treatments in PAYS in baseline were statistically significant (p=0.00) except regarding *control-combination* and *incentive-informative*. Regarding ISA1 all results were statistically significantly different (p=0.00). All results were statistically significantly different regarding ISA2 and ISA3. The difference between baseline driving behaviour in the four PAYS treatments is remarkable. This difference can probably not be fully explained by random variation but it might be due to relatively low numbers of participants in each group, i.e. a few deviating drivers might affect the result of the entire group.

PDA on 50 km roads appear in Table 5.4. *Control* had a PDA of 0.13, 0.11, 0.11, and 0.11 for baseline and the three ISA periods, respectively. Only baseline-ISA2 and baseline-ISA3 were statistically significantly different (p=0.02 and p=0.05, respectively). *Incentive* decreased from 0.08 in baseline to 0.04, 0.06, and 0.04 in the three ISA periods, respectively. All differences between baseline and ISA periods were statistically significant (p=0.00). ISA1-ISA2 and ISA2-ISA3 were also statistically significantly different (p=0.01 and p=0.00, respectively). ISA1-ISA3 were not statistically significantly different. A

Table 5.3. PDA for all driving included.

	Total				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	0.21	0.14	0.14	0.20	0.17
ISA1	0.22	0.04	0.08	0.05	0.08
ISA2	0.24	0.04	0.09	0.02	0.07
ISA3	0.27	0.04	0.10	0.02	0.10

Table 5.4. PDA for 50 km roads.

	50 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	0.13	0.08	0.07	0.14	0.17
ISA1	0.11	0.04	0.04	0.03	0.10
ISA2	0.11	0.06	0.05	0.02	0.10
ISA3	0.11	0.04	0.04	0.03	0.13

statistically significant reduction (p=0.00) was found regarding *informative* between baseline and the ISA periods while the differences between the ISA periods were not statistically significant. Also, a statistically significant reduction (p=0.00) was found regarding *combination* between baseline and the ISA periods while only ISA1-ISA2 were statistically significantly different during the ISA periods (p=0.01). Regarding ISA C PDA was 0.17, 0.10, 0.10, and 0.13 for baseline and the three ISA periods, respectively. All changes were statistically significant (p=0.00) except ISA1-ISA2. In baseline all results regarding PAYS differed statistically significantly (p=0.00) except *incentive-information*, which was just statistically significant (p=0.04) and *control-combination*, which were not statistically significantly different. *Incentive-information* was not statistically significantly different in the ISA periods at all. In ISA2 and ISA 3 were all statistically significantly different.

More remarkably different PDA results on 80 km roads in baseline and the three ISA periods appear in Table 5.5. *Control* was 0.28, 0.30, 0.30, and 0.36 regarding baseline and the three ISA periods, respectively. Only ISA1 and ISA3 differed statistically significantly from baseline (p=0.03 and p=0.00, respectively). *Incentive* was 0.20 in baseline and 0.05, 0.06, and 0.06 for the three ISA periods, respectively. All differences between baseline and ISA periods were statistically significant (p=0.00), however, no statistically significant differences appeared between the ISA periods. *Informative* baseline was lower than was *incentive* at 0.13 and it decreased to 0.09, 0.11, and 0.08 regarding the three ISA periods, respectively. All results differed statistically significantly from each other (p=0.00) except regarding ISA1-ISA3. *Combination* virtually eliminated speeding after activation of ISA. In baseline *combination* was 0.29 and it was followed by 0.02 in each of the three ISA periods, respectively. All differences were statistically significant (p=0.00) except ISA1-ISA2. Also remarkable reductions regarding *ISA C* appeared. *ISA C* was 0.16 in baseline and was reduced statistically significantly (p=0.00) to 0.08, 0.06, and 0.10 in the three ISA periods, respectively.

Table 5.5. PDA for 80 km roads.

	80 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	0.28	0.20	0.13	0.29	0.16
ISA1	0.30	0.05	0.09	0.02	0.08
ISA2	0.30	0.06	0.11	0.02	0.06
ISA3	0.36	0.06	0.08	0.02	0.10

Table 5.6. PDA for 110 km roads.

	110 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	0.09	0.19	0.25	0.16	0.24
ISA1	0.24	0.03	0.13	0.12	0.06
ISA2	0.33	0.03	0.11	0.03	0.05
ISA3	0.17	0.02	0.26	0.02	0.06

Also the differences between the ISA periods were statistically significant (p=0.00). In baseline all treatments were statistically significantly different (p=0.00) except regarding *control-combination*. Furthermore, the other differences between treatments in the ISA periods were statistically significant (p=0.00).

Remarkable, although slight effects can be found regarding 110 km roads. See Table 5.6. *Control* increased from 0.09 in baseline to 0.24, 0.33, and 0.17 in the three ISA periods, respectively. All differences were statistically significant. *Incentive* decreased from 0.19 to 0.03, 0.03, and 0.02 regarding baseline and the three ISA periods, respectively. All differences between baseline and ISA periods were statistically significant (p=0.00), however, no statistically significant differences appeared between the ISA periods. *Informative* changed from 0.25 in baseline to 0.13, 0.11, and 0.26 in the three ISA periods, respectively[25]. The differences between baseline and ISA1 and ISA2 were statistically significant (p=0.00), no statistically significant difference between baseline and ISA3 appeared. Also the ISA1-ISA2, ISA1-ISA3, and ISA2-ISA3 were statistically different (p=0.03, p=0.00, and p=0.00, respectively). *Combination* decreased from 0.16 to 0.12, 0.03, and 0.02 regarding baseline and the three ISA periods, respectively. All differences were statistically significant (p=0.00) except ISA2-ISA3. PDA regarding *ISA C* decreased markedly from 0.24 to 0.06, 0.05, and 0.06 regarding baseline and the three ISA periods, respectively. All differences between baseline and ISA periods were statistically significant (p=0.00) while only ISA1-ISA2 and ISA2-ISA3 were statistically significantly different (p=0.04 and p=0.03, respectively). In baseline all results were statistically significantly different (p=0.00). A similar situation appeared regarding ISA1 except regarding *informative-combination*, which was not statistically significantly different. In ISA2 and ISA3 PDA differed statistically significant (p=0.00) with exception of *incentive-combination*.

For 130 km roads only limited, although variable effects of ISA can be found. See Table 5.7. *Control* changed from 0.03 in baseline to 0.02, 0.08, and 0.02 in the three ISA periods, respectively. Baseline-ISA1 tended to be statistically significantly different (p=0.06). Also Baseline-ISA2, ISA1-ISA2, and ISA2-ISA3 were statistically significantly different (p=0.00). *Incentive* changed from 0.02 in baseline to

[25] This markedly increased PDA was due to two of the drivers, who increased their distance driven as well as their PDA in ISA3.

Table 5.7. PDA for 130 km roads.

	130 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	0.03	0.02	0.13	0.03	0.05
ISA1	0.02	0.02	0.04	0.06	0.01
ISA2	0.08	0.01	0.04	0.00	0.02
ISA3	0.02	0.01	0.07	0.00	0.03

0.02, 0.01, and 0.01 in the three ISA periods, respectively. All changes were statistically significant except baseline-ISA1 and ISA2-ISA3. More fluctuating results appeared regarding *informative*: 0.13, 0.04, 0.04, and 0.07 regarding baseline and the three ISA periods, respectively[26]. All were statistically significantly different (p=0.00) except ISA1-ISA3. *Combination* changed from 0.03 in baseline to 0.06, 0.00, and 0.00 in the three ISA periods, respectively. All differences were statistically significant (p=0.00) except ISA2-ISA3. *ISA C* decreased from 0.05 to 0.01, 0.02, and 0.03 for the baseline and the three ISA periods, respectively. PDA differed statistically significantly from baseline to ISA (p=0.00) while only ISA1-ISA2 and ISA1-ISA3 differed statistically significantly (p=0.04 and p=0.00, respectively). Baseline differed statistically significantly (p=0.00) between all treatments except *control-combination*. *Control-incentive* also differed statistically significantly, but with a p-value of 0.02. In ISA1 *control-informative* were statistically significantly different (p=0.02). The remaining differences in ISA1 were statistically significantly different (p=0.00). In ISA2 and ISA3 all changes were statistically significantly different (p=0.00). However, *incentive-combination* in ISA3 were statistically significantly different but with a higher p-value (p=0.03).

5.2.2 Summary and discussion

In general PDA in PAYS and ISA C decreased substantially after activation of ISA. The effect is most clear when violation of the speed limits results in penalty points linked to a relatively high financial penalty (*incentive*, and, *combination* in particular). On the other hand, when speed limit violation was linked to information alone or information and warnings combined with a minor financial incentive for avoiding speed limit violations, the effect was less clear. Also regarding maintenance of the effect of ISA there seems to be a statistically significantly higher effect of *incentive*, and *combination* in particular in PAYS, while the other effects are diminishing over time. These results are clear regarding the total amount of driving and regarding driving on 50 and 80 km roads while they are less certain as to 110 and 130 km roads. However, it should be borne in mind that driving on 50 and 80 km roads covers the major part of the distance driven included in this study.

[26] The unexpectedly high PDA for baseline informative is due to the fact that two of drivers drove 90% of the total PDA and that the total distance driven on 130 km roads is relatively low (approximately 15% of the total included distance driven).

When PDA for PAYS *combination* is compared with results from other ISA trials, it appears that there might have been a bigger effect from *combination* than from most ISA in trials in other countries. In PAYS combination the most significant effects appear on 80 km roads although remarkable effects have also been recognised on 50 km roads. The results from some ISA trials indicate a similar tendency. In the *Ghent* ISA trial the effect on PDA was minor on 50 km roads (1.6 percentage points (%)) while it was 9.7% on 90 km roads (Vlassenroot et al. 2006). Also, in the *ISA UK* trial the most marked effect was found for 70 mph roads (11.1%) while it was approximately 6-7% on the other road types showing statistically significant results (Carsten et al. 2008). In contrast to this an almost equivalent effect across different road types was found regarding the trials in *Borlänge* and *Lund*, where an almost identical effect was recognised for 50, 70, and 90 (Borlänge, only) km roads. (Biding, Lind 2002).

Hence, regarding PAYS *combination* parallel effects can be found in other ISA trials: biggest effect on road with higher speed limits, although the effect in PAYS seemed to be higher than in other trials.

The effect over time remained stable in the PAYS *combination* and *incentive* in the medium term (3-4.5 months with active ISA). This stability differs somewhat from the results of the Ghent trial and the *Lund* and *Borlänge* trials, in which the effect on PDA decreased over time. However, the results in the Swedish trials were regarding long-term use (7 months on average) (Várhelyi et al. 2004) and hence not directly comparable with the PAYS ones. On the other hand, also the successor of the *Borlänge* trial, which used incentive linked to speed violation, showed decreasing effect over time - especially if any risk of receiving negative incentives was removed. Moreover, in the Dutch incentive-based ISA trial the proportion of time driven above the speed limit was markedly reduced but a slightly decreased effect over time was found.

PDA in general decreases due to ISA. However, unless an incentive associated with avoiding speeding is included the effect seems to decrease over time. Also, the higher effect on roads with higher speed limits (80 and 110 km roads vs. 50 km roads) is mainly due to more speeding in baseline. And it is consistent with the questionnaire results from the *SARTRE* study and the questionnaire from the *INFATI* trial, which showed that drivers found that they sped the most on roads with high speed limits (Nielsen, Boroch 2001, Cauzard 2004).

5.3 MFFS

5.3.1 Results

MFFS speed is calculated for each road type, not for the total distance driven, because MFFS is associated with the speed limit, and therefore, it would not give valid results if FCD from several road types were merged - the purpose being to estimate the effect of ISA. MFFS for 50 km roads appears in Table 5.8.

Regarding *control* MFFS remained virtually unchanged with 47.5 - 47.7 km/h. None

Table 5.8. The level of MFFS for 50 km roads (km/h).

	50 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	47.7	46.3	46.0	47.8	48.6
ISA1	47.7	45.8	45.4	45.8	47.1
ISA2	47.5	46.3	45.7	45.8	47.2
ISA3	47.5	46.2	45.7	45.8	48.0

of the results were statistically significantly different. Baseline *incentive* was 46.3 km/h. It was reduced to 45.8 km/h in ISA1 and afterwards it returned to virtually the same value as in baseline. Only baseline-ISA1 decreased statistically significantly (p=0.00) while there was no statistically significant difference regarding baseline-ISA2 and baseline-ISA3. In the ISA periods ISA1 differed statistically significantly from ISA2 and ISA3 (p=0.00) while ISA2-ISA3 did not. Baseline *informative* was 46.0 km/h and decreased to 45.4, 45.7, and 45.7 km/h for the three ISA periods, respectively. Only ISA1 and ISA2 differed statistically significantly from baseline (p=0.00 and p=0.04, respectively). Baseline *combination* was 47.8 km/h with a statistically significant decrease (p=0.00) to 45.8 km/h in the ISA periods. There were no differences within the ISA periods. For *ISA C* the baseline was 48.6 km/h. It decreased to 47.1 km/h after which it increased again to 47.2 and 48.0 km/h for the two last ISA periods, respectively. All were statistically significantly different from baseline. ISA1-ISA2 tended to differ statistically (p=0.06) significantly while ISA1-ISA3 and ISA2-ISA3 differed statistically significantly (p=0.00). In baseline all results were statistically significantly different (p=0.00) except *control-combination* and *incentive-informative*. In ISA1 all results were statistically significantly different (p=0.00) except *incentive-combination*. Likewise in ISA2 except for *informative-combination*, which tended to differ statistically significantly (p=0.09). In ISA3 all results differed statistically significantly (p=0.00) except *incentive-combination*, which differed statistically significantly with p=0.01, and *informative-combination*, which did not.

The effect on MFFS on 80 km roads appears in Table 5.9. Baseline *control* was 82.8 km/h, changing to 83.3, 82.5, and 83.5 km/h for the three ISA periods, respectively. Only ISA1 and ISA3 differed statistically significantly from baseline (p=0.00). ISA1-ISA2 and ISA2-ISA3 differed statistically significantly while ISA1-ISA3 tended to do so (p=0.07). Baseline *incentive* decreased from 80.3 to 78.5, 78.6, and 78.6 km/h for the three ISA periods, respectively. The decrease was statistically significant regarding all three ISA periods

Table 5.9. The level of MFFS for 80 km roads (km/h).

	80 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	82.8	80.3	78.8	82.3	80.4
ISA1	83.3	78.5	77.6	77.6	77.7
ISA2	82.5	78.6	78.5	78.0	77.3
ISA3	83.5	78.6	77.8	78.5	78.8

(p=0.00). Also ISA1-ISA2 and ISA1-ISA3 differed statistical significantly (p=0.00). A more confounding pattern can be found regarding *informative*. MFFS was 78.8, 77.6, 78.5, and 77.8 km/h for baseline and the three ISA periods, respectively. All results differed statistically significantly with p=0.00 and baseline-ISA2 with p=0.01. A markedly reduced MFFS was found for *combination*. It decreased from 82.3 to 77.6, 78.0, and 78.5 km/h for baseline and the three ISA periods, respectively. In spite of a minor increase during the ISA periods, the MFFS remained significantly below the level in baseline. All results differed statistically significantly (p=0.00). A substantial although decreasing effect can be found for *ISA C*. Here the baseline was reduced from 80.4, to 77.7, 77.3, and 78.8 km/h for the ISA periods, respectively. Baseline-ISA1 and baseline-ISA2 differed statistically significantly (p=0.00) while baseline-ISA3 did not. ISA1-ISA3 and ISA2-ISA3 differed statistical significantly (p=0.00). In baseline in PAYS all results were statistically significantly different (p=0.00). In ISA1 all results differed statistically significantly (p=0.00). In ISA2 and in ISA3 all results differed statistically significantly. All except *incentive-combination* were with p=0.00 while the last mentioned had a p-value of 0.02.

Results regarding MFFS for 110 km roads appear in Table 5.10. Baseline *control* was 108.0 km/h and changed to 110.0, 112.8, and 108.3 km/h in the three ISA periods, respectively. Only ISA1 and ISA2 differed statistically significantly from baseline (p=0.00). All results in the ISA periods differed statistically significantly (p=0.00). For *incentive* MFFS decreased markedly from 108.4 to 105.5, 106.0, and 106.8 km/h in the three ISA periods, respectively. All differed statistically significantly (p=0.00) except baseline-ISA2, which had a p-value of 0.01. A similar pattern appears regarding *informative* although the level in ISA3 is equivalent to baseline. Here the MFFS was 111.1, 108.9, 108.2, and 111.1 km/h in the four periods, respectively. All results differed statistically significantly (p=0.00) except baseline-ISA3. Regarding *combination* MFFS increased at different levels in the ISA periods. It was 107.5, 109.5, 107.6, and 108.7 km/h in the baseline and the three ISA periods, respectively. ISA 1 and ISA3 differed statistically significantly from baseline (p=0.00). Statistically significant differences appeared within the ISA periods (p=0.00) as well. It should be noted that this increase in ISA1 is mainly due to one driver who had a particularly high MFFS in ISA1. For *ISA C* baseline was 111.1 km/h while it was 106.5, 105.2, and 105.4 km/h for the three ISA periods, respectively. Baseline-ISA1 differed statistically significantly while there were no statistically significant

Table 5.10. The level of MFFS for 110 km roads (km/h).

	110 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	108.0	108.4	111.1	107.5	111.1
ISA1	110.0	105.5	108.9	109.5	106.5
ISA2	112.8	106.0	108.2	107.6	105.2
ISA3	108.3	106.8	111.1	108.7	105.4

differences between baseline and the two other ISA periods (p=0.00). In the ISA periods ISA1-ISA2 and ISA1-ISA3 differed statistically significantly (p=0.00). In baseline only *control-informative*, i*ncentive-informative*, and *informative-combination* differed statistically significantly (p=0.00). In ISA1 all results differed statistically significantly (p=0.00) except informative-combination. In ISA2 all results differed statistically significantly (p=0.00) except *incentive-combination* and *informative-combination*. In ISA3 all results differed statistically significantly (p=0.00) except *control-combination*, which were statistically significantly different with a p-value of 0.02.

For 130 km roads fluctuating results have been found. See Table 5.11. *Control* remained virtually unchanged in baseline and the two first ISA periods while it decreased considerably in ISA3. MFFS was 119.2, 119.4, 119.5, and 115.6 km/h for the four periods, respectively and only ISA3 differed statistically significantly from the other periods (p=0.00). *Incentive* increased from 117.5 to 119.1, 118.6, and 119.6 km/h in the three ISA periods, respectively. All results differed statistically significantly from each other (p=0.00). Regarding *informative* was MFFS 123.6, 122.5, 121.2, and 124.7 km/h for the baseline and the three ISA periods, respectively. All results differed statistically significantly from each other (p=0.00). *Combination* decreased from 123.3 to 120.8, 119.1, and 121.2 km/h in the three ISA periods, respectively. All results differed statistically significantly from each other (p=0.00) except baseline-ISA1, which differed statistically significantly with a p-value of 0.05. *ISA C* increased after activation of ISA. With 119.2 km/h in baseline and 120.2, 119.8, and 121.1 km/h in the three ISA periods, respectively. All differed statistically significantly (p=0.00) except ISA1-ISA2. In baseline regarding PAYS all results differed statistically significantly (p=0.00). In ISA1 all results differ statistically significantly except *control-incentive* (p=0.00). In ISA2 all results differed statistically significantly (p=0.00) except *incentive-combination* and *control-combination.* In ISA3 all results differed statistically significantly (p=0.00). In general, on 130 km roads the results were rather deviating. Also, it is worth noting that in all cases MFFS was considerably below the speed limit.

5.3.2 Summary and discussion

In general MFFS changed the most on 50 km roads due to *combination*. *Incentive* and *informative* resulted in reductions although they faded in time. In *ISA C* also a significant although somewhat decreasing effect appeared. On 80 km roads a stable although minor effect can be found for *incentive* while it is more confounding re-

Table 5.11. The level of MFFS for 130 km roads (km/h).

	130 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	119.2	117.5	123.6	123.3	119.2
ISA1	119.4	119.1	122.5	120.8	120.2
ISA2	119.5	118.6	121.2	119.1	119.8
ISA3	115.6	119.6	124.7	121.2	121.1

garding *informative*, which is only statistically significantly lower than baseline in some periods. The most remarkable reductions appeared for *combination*, which, despite a decreasing effect, remain more than twice as big as for the other treatments. For 110 km roads the most remarkable effects appear regarding *ISA C*. For PAYS the *incentive* results in the most reduced MFFS, although the effect was somewhat decreasing. Also *informative* affected the MFFS somewhat but the effect diminished over time. *Combination* did not result in reduced MFFS and it increased in two of the ISA periods. On 130 km roads no clear effects can be found. However, *combination* resulted in the only lasting reduction in MFFS. Overall, the difference between the treatments in baseline in many cases appears to be more substantial than the differences during each treatment. Although *combination* has significantly bigger effect on the road types constituting the major part of the distance driven in the trial (50 and 80 km roads), this is partly due to a considerably higher starting point, especially on 80 km roads, than for other ISA treatments. The reductions in MFFS for PAYS *combination* were considerably higher on 50 and 80 km roads than they were for the *TAC Safecar* trial. In the latter the reductions were 1.1, 1.4, and 0.9 km/h on 60, 80, and 100 km roads, respectively. Reductions in MFFS were likewise found for 50 and 70 km roads but they were not statistically significant (Regan et al. 2006b). In PAYS they were from 2.0 and up to 4.7 km/h on 50 and 80 km roads, respectively. One of the reasons for the smaller effect in the *TAC Safecar* trial is that speeding was low already in the baseline period.

Despite the somewhat confounding results regarding MFFS it appeared that incentive and information and warnings combined given immediately (PAYS *combination*) had a clearer and more lasting effect than had postponed incentives (PAYS *incentive*) and information without incentives (PAYS *informative*). Thus the results regarding 50 and 80 km roads are consistent with the general theories about incentives. A more confounding result appears regarding 110 and 130 km roads.

5.4 FFSD

5.4.1 Results

FFSD on 50 km roads in baseline and the three ISA periods appear in Table 5.12. Baseline *control* was 8.2 km/h while it decreased slightly to 7.6, 7.8, and 7.5 km/h in the three ISA periods, respectively. Baseline-ISA1 and baseline-ISA3 were statistically significantly different ($p=0.01$ and $p=0.00$, respectively), while baseline-ISA2 tended to be statistically significantly different ($p=0.08$). Between the ISA periods only ISA2-ISA3 tended to be statistically significantly different

Table 5.12. The level of FFSD for 50 km roads (km/h).

	50 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	8.2	8.0	7.0	8.6	9.5
ISA1	7.6	6.5	6.2	5.8	8.2
ISA2	7.8	6.7	6.5	5.6	8.0
ISA3	7.5	6.4	6.2	5.8	8.7

(p=0.07). More significant results can be found regarding *incentive*, where FFSD decreased from 8.0 to 6.5, 6.7, and 6.4 km/h in baseline and the three ISA periods, respectively. All ISA periods differed statistically significantly from baseline (p=0.00). In the ISA periods only ISA1-ISA2 tended to be statistically significantly different (p=0.07). Less remarkable reductions can be found for *informative*. It should be noted that the ISA results of 6.2, 6.5, and 6.2 km/h, respectively, were virtually equal to the *incentive* results while at 7.0 km/h the baseline result was considerably lower than it was for *incentive*. All differences between baseline and the three ISA periods were statistically significant, but there were no statistically significant differences between the ISA periods. *Combination* resulted in the most remarkable reductions in FFSD, which decreased from 8.6 to 5.8, 5.6, and 5.8 km/h, respectively. All were statistically significantly lower than baseline (p=0.00) while there were no statistically significant differences between the results in the ISA periods. Also, a reduction in FFSD was found regarding *ISA C*, where it decreased statistically significantly (p=0.00) from 9.5 to 8.2, 8.0, and 8.7 km/h in baseline and the three ISA periods, respectively. In the ISA periods ISA1-ISA3 and ISA2-ISA3 were the only statistically significant differences (p=0.00). In baseline all results regarding PAYS except *control-incentive* and *control-combination* were statistically significantly different. All results regarding PAYS in ISA1 were statistically significantly different (p=0.00) except *incentive-informative*, which were just statistically significantly different (p=0.04) and *informative-combination*, which were not. In ISA2 all were statistically significantly different (p=0.00) except regarding *incentive-informative*, which were just statistically significantly different (p=0.04). In ISA3 all were statistically significantly different (p=0.00) except regarding *incentive-informative*, which were just statistically significantly different (p=0.03) while *informative-combination* were not.

The FFSD on 80 km roads appears in Table 5.13. *Control* varied somewhat: from 10.7 km/h in baseline to 11.6, 10.1, and 11.0 km/h in the three ISA periods, respectively. Only ISA1 and ISA3 differed statistically significantly from baseline (p=0.00). In the ISA periods all except ISA1-ISA3 differed statistically significant from each other (p=0.00). A considerably higher effect was found for *incentive*, FFSD decreasing from 10.8 to 6.9, 6.5, and 6.8 km/h in baseline and in the three ISA periods, respectively. All were statistically significantly different from baseline. In the ISA periods ISA1-ISA3 and ISA2-ISA3 differed statistically significantly (p=0.03 and p=0.00, respectively) while ISA1-ISA2 were not. *Informative* ISA resulted in a considerable

Table 5.13. The level of FFSD for 80 km roads (km/h).

	80 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	10.7	10.8	9.5	11.0	11.0
ISA1	11.6	6.9	8.3	5.3	9.6
ISA2	10.1	6.5	9.9	5.3	8.5
ISA3	11.0	6.8	10.9	5.4	9.7

reduction in FFSD: 9.5 km/h in baseline and 8.3 km/h in ISA1. However, FFSD increased above the baseline level to 9.9, and 10.9 km/h in the two last ISA periods, respectively. ISA1 was statistically significantly different from baseline (p=0.00) while for ISA2 (p=0.08) it tended to be. ISA3 did not differ statistically significantly from baseline. In the ISA periods only ISA1-ISA2 and ISA1-ISA3 differed statistically significantly from each other (p=0.00). FFSD was virtually halved with *combination*. It decreased statistically significantly from 11.0 to 5.3, 5.3, and 5.4 km/h in baseline and in the three ISA periods, respectively. In the ISA periods only ISA1-ISA3 tended to differ statistically significantly from each other (p=0.06). Also, considerable reductions were found for *ISA C*, FFSD decreasing statistically significantly from 11.0 to 9.6, 8.5, and 9.7 km/h in baseline and in the three ISA periods, respectively. In the ISA periods all results differed statistically significantly (p=0.00). In baseline *incentive-combination* were not statistically significantly different. *Control-incentive* and *control combination* were statistically significantly different (p=0.03 and 0.01, respectively) and so were the remaining comparisons (p=0.00). All differences between treatments in the ISA periods were statistically significantly different (p=0.00).

In Table 5.14, appear results regarding 110 km roads. FFSD for *control* increased considerably from 7.0 to 9.5, 11.8, and 8.7 km/h in baseline and in the three ISA periods, respectively. All differences except ISA1-ISA3 were statistically significant (p=0.00). *Incentive* was reduced considerably from 9.0 km/h in baseline to 6.2, 5.9, and 5.9 km/h in the three ISA periods, respectively. All reductions except regarding ISA1-ISA3 were statistically significantly different (p=0.00). *Informative* decreased considerably from baseline to ISA1 with a FFSD of 10.7 and 7.3 km/h, respectively. Afterwards it increased again to 9.2 and 12.6 km/h in the two last ISA periods, respectively. All changes except regarding ISA1-ISA2 were statistically significant (p=0.00). *Combination* increased after activation of ISA. However, this increase was not statistically significant. Afterwards it decreased markedly compared to baseline, going from 8.8 to 10.7, 7.3, and 5.3 km/h in baseline and in the three ISA periods, respectively. All changes but baseline-ISA1 were statistically significant (p=0.00). Marked reductions were likewise found regarding *ISA C*, where FFSD decreased statistically significantly from 15.6 to 8.4, 8.3, and 8.6 km/h in baseline and in the three ISA periods, respectively (p=0.00). Within the ISA periods, only ISA1-ISA3 differed statistically significantly (p=0.04). It should be noted that significantly higher FFSD appeared in baseline here than

Table 5.14. The level of FFSD for 110 km roads (km/h).

	110 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	7.0	9.0	10.7	8.8	15.6
ISA1	9.5	6.2	7.3	10.7	8.4
ISA2	11.8	5.9	9.2	7.3	8.3
ISA3	8.7	5.9	12.6	5.3	8.6

for the PAYS treatments. In baseline all treatments were statistically significantly different with p=0.00 (p=0.02 regarding *incentive-informative*), except *incentive-informative* and *informative-combination*, which were not. In ISA1 all except *control-combination* were statistically significantly different (p=0.00). In ISA2 all except *informative-combination* were statistically significantly different (p=0.00), and in ISA3 all were statistically significantly different (p=0.00).

In Table 5.15 it appears that FFSD on 130 km roads for *control* differs somewhat within the four periods. It was 9.0 km/h in baseline, while it was 8.3, 11.0, and 9.8 km/h in the three ISA periods, respectively. Only ISA2 and ISA3 differed statistically significantly from baseline (p=0.00 and p=0.01, respectively). In the ISA periods all except ISA2-ISA3 were statistically significantly different from each other (p=0.00). *Incentive* decreased infinitesimally from 9.0 to 8.9, 8.4, and 8.7 km/h in baseline and in the three ISA periods, respectively. Only ISA2 differed statistically significantly from baseline (p=0.00) while ISA3 tended to do so (p=0.06). ISA1-ISA2 and ISA2-ISA3 differed statistically significantly (p=0.00 and p=0.03, respectively) while ISA1-ISA3 did not. *Informative* differs somewhat within the four periods being 10.3 km/h in baseline and 8.2, 10.8, and 9.5 km/h in the three ISA periods, respectively. ISA1, ISA2, and ISA3 were statistically significantly different from baseline (p=0.00, p=0.02, and p=0.00, respectively). In the ISA periods all except ISA2-ISA3 were statistically significantly different (p=0.00). *Combination* decreased somewhat after activation of ISA. FFSD went from 8.8 km/h in baseline, to 8.7, 7.3, and 8.1 km/h in the three ISA periods, respectively. All were statistically significantly different from each other (p=0.00). For *ISA C* a reduced FFSD was found after activation of ISA with a decrease from 10.5 to 9.0 km/h in baseline and ISA1. Then it increased to 9.4 and 9.7 km/h in ISA2 and ISA3, respectively. ISA1 and ISA3 differed statistically significantly from baseline (p=0.01) while ISA2 did not. In the ISA periods all except ISA2-ISA3 differed statistically significantly (p=0.00). In baseline all except *informative-combination* were statistically significantly different. In ISA1 *control-informative* were statistically significantly different with (p=0.05) while the rest were statistically significantly different with p=0.00. In ISA2 all except *incentive-combination* differed statistically significantly (p=0.00). In ISA3 *control* differed statistically significantly from *incentive* and *combination* (p=0.01) and tended to differ statistically significantly from *information* (p=0.06). Overall, results regarding 130 km roads differ somewhat. There seems not to be a strong connection between activation of ISA and FFSD.

Table 5.15. The level of FFSD for 130 km roads (km/h).

	130 km roads				
	PAYS Control	PAYS Incentive	PAYS Informative	PAYS Combination	ISA C
Baseline	9.0	9.0	10.3	8.8	10.5
ISA1	8.3	8.9	8.2	8.7	9.0
ISA2	11.0	8.4	10.8	7.3	9.4
ISA3	9.8	8.7	9.5	8.1	9.7

5.4.2 Summary and discussion

In general FFSD in PAYS and ISA C decreased substantially after activation of ISA. The effect was most apparent where violating the speed limits results in penalty points associated with a relatively high financial penalty (*incentive* and in particular *combination*), while in cases where any speed limit violation was associated with information and warnings only (*informative*) or information, warnings and a small incentive for avoiding speeding the effect was less persistent (*ISA C*). These results are clear regarding driving on 50 and 80 km roads while they are less certain on 110 and 130 km roads. It should be noted that the occasional apparent lack of connection between the difference between FFSD and the level of statistically significant difference regarding 110 and 130 km roads cannot be explained. Calculation approaches have been checked carefully, and no reasons for these results appeared. However, two circumstances need to be stated: 1: the distances driven on 110 and 130 km roads are considerably shorter regarding ISA C than for the other road types and treatments, a fact which will increase the effect of a single driver's major driving deviation considerably. And 2: regarding 130 km roads it is plausible that the limited effect of ISA, which has been documented in earlier results, confounds results and creates far more deviating results than can be attributed to ISA. Overall, the results regarding 110 and 130 km roads should be treated with reservation while it is plausible that results regarding 50 and 80 km roads are more reliable.

In PAYS *combination* the most significant effects appear on 80 km roads although remarkable effects have also been recognised on 50 km roads regarding FFSD. In the *PROSPER* trial in Spain it was found, somewhat similarly to the Danish results, that the largest effect appeared on 80 km roads while the effect was limited on 50 km roads. In contrast to the results from the Danish ISA trials carried out on high-speed roads, a substantially increased SD was found on 120 km roads. (Adell, Várhelyi & Hjälmdahl 2008). Minor effects on SD were found in the *Ghent* ISA trial. However, it seems that in this trial the most remarkable results are to be found for 90 km roads although it is not stated whether, statistically, this effect is significantly bigger than for other road types (Vlassenroot et al. 2006). In Lund the biggest reductions in SD were found on 70 km arterial roads. However, it should be noted that these results were based on driving in selected spots and mid-blocks only, and that they are distributed on other road types than in other trials, which makes the results hard to compare. In the *TAC Safecar* trial statistically significant although smaller reductions in FFSD were likewise found (Regan et al. 2006b). It seemed that there was not a substantial difference between the results regarding various road types. As for the *TAC Safecar* trial, it should again be noted that speed limit observance was highlighted by the Victorian authorities during the ISA trial, which might have diminished the actual effect of ISA. Direct comparison across various trials should be made with care as many other factors affect the results and because with the exception of the *TAC Safecar* trial the other results were based on SD and not FFSD. It is reasonable to believe that SD changes less due to confounding effects of driving at low speeds. Overall, the results concerning FFSD exhibit the same tendencies as other results from the Danish ISA trials.

On the basis of driving behaviour on 50 and 80 km roads it seems that the results fit well with the general theories about how incentive work. Information and warnings about speeding and the incentives associated given immediately (PAYS *combination*) had a significantly bigger effect than incentive given later (PAYS *incentive*) and information given without incentive (PAYS *informative*). It also appeared that the relatively weak and postponed incentive combined with information (*ISA C*) had a minor effect. Thus the results are consistent with the general theories about incentives. Incentives given immediately work better than postponed incentives and monetary incentives work better than do non-monetary incentives. A more confounding result appears regarding 110 and 130 km roads, but as discussed above driving on these road types only covers a minor part of the total distance driven.

5.5 Validity of results

Before concluding the present thesis, a few considerations concerning the validity of the results will be presented. Validity being assessed on the basis of the description in the *Handbook of Road Safety Measures* (Elvik et al. 2009), four types of validity are selected to assess the results of the Danish ISA trials: statistical validity; theoretical validity; external validity, and internal validity.

5.5.1 Statistical validity

Statistical validity can be defined as the extent of numerical accuracy, faultlessness, and representativity in the study. Results can be seen as statistically valid if 1: there is low likelihood that random variations affect the results; 2: the results are not affected by systematic measuring errors; 3: have a known numerable uncertainty concerning the calculated results; and 4: are representative of a known population of units.

It is assessed that the results of the Danish ISA trials have a high statistical validity. As the drivers were randomly assigned into the different ISA treatments and their assignment was scrutinised to control for any inappropriate skewness in the socio-economic data, there is little likelihood that random variations are significant for the results. The use of FCD as the basis for the estimated safety effects causes low likelihood of measuring errors in the results - be there any error in data, it is not likely that it will result in measurement errors. Also, all driving data regarding the participant in the periods fulfilling the requirements are included in the calculation of the results. Hence the uncertainty concerning the calculated results is known and non-existent. Moreover, the entire population in the ISA trial who met the age limit requirements of the study are included. Hence the acquired results are representative of the entire population in the trial.

5.5.2 Theoretical validity

Theoretical validity can be seen as the theoretical foundation and the operational definitions of theoretical concepts and propositions. Criteria for theoretical proportions are: identification of relevant concepts and variables, hypotheses describing the relationship between variables, and knowledge of causal mechanisms.

Basically, it is assessed that the theoretical validity is high. The effect of ISA was measured by changes in driving speed, exemplified by PDA and MFFS, and by speed variation, exemplified with FFSD. Speed variation and, in particular, excessive speeds, are well documented as measures for road safety - the former by the studies by Salusjärvi and by Finch, the latter by the Nilsson's well-reputed Power Model. Consequently, it is assessed that there is a high theoretical validity regarding the selected measures and the effect on road safety. Also, there is accordance between the theories of incentive and how driving behaviour was affected by ISA. Incentive has an effect and an incentive given immediately has higher effect than one given later, as found by Hattem & Mazureck, Hagenzieker et al., and by Luo et al. There seems to be a connection between the delay of information about incentive and the effect. This result might, however, be due to the fact that the incentive given immediately (*combination* in PAYS) was markedly bigger than the incentive given later (*ISA C*). On the other hand the results of *incentive* (information about any incentive was given after a trip) indicate that delayed feedback results in less effect of any incentive. Hence, the trials meet the requirements of measuring causal mechanisms between the used variables and the anticipated effects satisfied the hypotheses for the effects of various types of incentives and how ISA would affect driving behaviour.

5.5.3 External validity

External validity can be seen as the opportunity to generalise the results of a study to other populations and contents. Comparing results with the results of studies covering the same measure offers a possibility to assess external validity. The results are found to have a high external validity if they are stable over time and space and across society and timespan. Furthermore, the external validity of the results is regarded as high if they are stable across various research methods, or show a pattern, which can be explained on the basis of known conditions characteristic of each study.

Offhand the results of the Danish ISA trials do not have a strong external validity due to the fact that in several ISA trials, including PAYS, the participating drivers were found to be less keen on speeding than the average drivers in the population they belonged to, as mentioned in section 2.3. So there might be a self-selection problem in such trials: participants who are less keen on speeding will be more positive towards participating in ISA trials, because they do not expect any ISA equipment to affect their driving behaviour substantially. Therefore, this group of drivers could be overrepresented in such trials. Contrary to this, the results can with deviations be recognised in most ISA trials. On the basis of various ways of measuring the effect of ISA on driving behaviour the results broadly converge: ISA reduces speeding and speed variation substantially.

The decreasing effect of ISA found for ISA C, in which a proportion of involuntary drivers participated, probably reflects the effect of ISA on the average drivers better than in most other trials. However, the incentive in ISA C was much weaker than in PAYS, which points towards a stronger external validity. Also, results reasonably have stronger validity regarding the subgroup of drivers who observe the speed limits and only violate them by inattention. But it seems obvious that a generalisation of the results would not take into account the effect (if any) on the drivers who speed the most and therefore have the highest need for ISA. Therefore, there is a lack of validity across society, and, in summary, the external validity is not strong.

It is, however, reasonable that, despite the absence of a strong external validity, the results are at least as valid as found regarding most other ISA trials.

5.5.4 Internal validity

Internal validity refers to the inference of a causal relationship between a presumed treatment and a presumed effect. This aspect of validity is central and implies statistical validity as well as the fulfilment of the requirements for external validity and theoretical validity.

Internal validity is found to be acceptably high although external validity is low. Despite this, there seems to be a clear causal relationship between the ISA treatment, the various types of incentives interrelated to the treatments and the effect on driving behaviour found in the study. Neither technical problems with the ISA equipment nor drivers who stopped prematurely in the trial are assessed to significantly affect the results found, as mentioned in section 4.1. If there is any effect of premature exit caused by dislike of the ISA conditions, it is limited, because only a few participants dropped out for this reason. The low number of participants in the various groups might have affected results. Despite the fact that the drivers were randomly assigned into the four groups involving different ISA conditions, a possible impact on the effect of ISA caused by differences between the groups cannot be dismissed. However, scrutiny of the socio-economic data has not resulted in any clear reasons for any bias. Moreover, the results, which show an increasing level of speeding in the control group, underpin the validity of the actual results.

However, the external validity is not strong; the participating drivers were less keen on speeding than is the average driver, and in most ISA trials it is found that participants in general are more positive towards ISA than is the average driver. Consequently, the internal validity is not convincing although it does seem reasonable that it is as reliable as the internal validity in most ISA trials.

6 Summary and conclusion

6.1 Summary

Despite massive improvements in vehicles' safety equipment, more information and safer road network, inappropriate road safety is still causing that more than 1.27 million people globally are killed and 50 million injured each year. Fortunately, increased welfare results in a disconnection between economic growth and increased road risk. Until a few years ago the number of fatalities in most countries had decreased year by year while the amount of traffic increased. However, this trend has been replaced by a more uncertain development towards a constant or even somewhat increasing risk.

Inappropriate speeding and high speed variation are central causes for the high number of fatalities on the roads. Despite the introduction of speed limits and the subsequently reduced number of fatalities, speed limit violating driving behaviour is still widespread, also in countries with high road safety levels. Traditional solutions to prevent speed violation have been enforcement, information, and enhanced road design. It seems hard to achieve sufficient further road safety on the basis of these solutions, while additional solutions based on information technology (IT) in vehicles might further improve the road safety level. Some of these systems, known as Intelligent Transport Systems (ITS), and more particularly Intelligent Speed Adaptation (ISA), can be seen as a central solution towards a safer road network.

ISA can give feedback in a number of ways. It can be *informative*. It informs the driver about the speed limit for a particular location. ISA can also be *warning* and give feedback if the speed limit is violated. Also, ISA can be *recording*, which means that driving behaviour is logged and driving data can be used for a number of purposes. ISA can also be *incentive*. Incentive ISA is based on recording ISA but is supplemented with a kind of reward or penalty system interrelating driving behaviour and reward/penalty. Furthermore, ISA systems can be *intervening*, which means that they can prevent speed violations physically.

So far more than 30 ISA trials involving different ISA equipment have been carried out, and almost all trials have shown significant effects on driving behaviour towards fewer speed limit violations and more appropriate driving behaviour. Estimation of safety effects showed various results depending on several factors and the reduction in the number of fatalities was estimated to be as high as 37 to 42% in some studies if ISA was fully implemented.

Despite convincing effects of ISA in short term, it was found that the effect of ISA decreased over time and that the participating drivers were more positive towards ISA than were other drivers. Also, it was found that exposed road users, such as young novice drivers, were underrepresented in most trials. However, despite the general effectiveness of ISA and users' approval of the systems, only warning ISA, which can easily be ignored, has been on the market, and only since late 2008.

Could it be that an economic incentive linked to driving behaviour could be the determining factor that might open the market to ISA on a large scale? This was the underlying idea when two Danish ISA trials were developed involving an incentive-based ISA system aimed at the target groups of young drivers and commercial drivers, on a commercial basis.

The trials were *Pay As You Speed* (PAYS) and *Intelligent Speed Adaptation Commercial* (ISA C). In PAYS the size of the insurance rate would depend on the driver's amount of speeding. Thus no speeding would result in a 30 per cent reduction on the car insurance rate. The ISA C, a small-scale concurrent ISA trial aimed at commercial drivers, had only a weak incentive in the form of social control plus monthly and final rewards to the drivers with the fewest and smallest speed violations.

In both trials the feedback system to the driver consisted of a display with loudspeakers, a small computer and a GPS antenna. Feedback was given, if the speed exceeded the speed limit by more than 5 km/h. The display would show the actual speed limit, any penalty points received due to speeding during the ongoing trip, and the number of penalty points received during the previous test period. Additionally, auditory feedback would be given in the case of speeding every six seconds. From the third and subsequent warnings penalty points would be added to each warning. At the end of a trip, the participant driver could see any received penalty points on a personal webpage. In the case of the ISA C, also a personal key ID was handed out to all participants, some of the cars having more than one driver.

The set target for PAYS was to have 300 young car drivers participate over a period of three years. However, recruitment turned out to be very difficult and the trial ended up with 153 participants distributed among all of the age categories but with a majority of young drivers.

The first 1.5 months - the baseline period during which the ISA was not activated - was used to assess each participant's *normal* driving behaviour. The bonus was independent of the driving behaviour during this period. During the following 4.5 months, the participants were randomly divided into four groups, each driving under different ISA conditions. A *control* group continued like in baseline: no information or warnings and no reduction in the discount were given. An *incentive* group continued with no real-time feedback. However, penalty points were available on the personal webpage and would result in reduced discount on the insurance rate. An *information* group was given only information and warning, however, their driving behaviour did not affect the discount. In a *combination* group, the participants received information, warnings, and any reduced discount in case of speeding. The *combination* treatment was the main mode for the trial, and after the first 6 months, all participants drove in this mode until the trial was interrupted. This segregation made it possible to measure the effect of each part of the ISA system: incentive alone, information and warnings alone, and these combined.

The *ISA C* involved 26 commercial cars with 51 drivers for approximately one year. The first approximately 2 months was a baseline period. After the activation of ISA, the driving behaviour of each driver and each car was calculated monthly. The monthly reward was a shopping basket worth about € 40. Moreover, the final top ten drivers received a navigation system for their private cars. Finally, social control within each company might have worked as an incentive. The monthly and final rewards were meant as an incentive in order to achieve a similar effect to PAYS.

FCD were used to measure the effect of ISA on driving behaviour. Only results on driving behaviour on roads with 50, 80, 110, and 130 km/h speed limits are included in this thesis. And, only drivers aged 18-28 years are included from PAYS while all vehicles involved from the ISA C trial are included.

6.2 Conclusion

The aim of this thesis was to establish how informative and warning ISA in combination with different types of incentives for avoiding speeding affect driving behaviour among exposed road users in short term and in medium term after activation of ISA. The effect was studied on the basis of the two Danish ISA trials *PAYS* and *ISA C*. The research question was as follows:

How are exposed groups of drivers' driving behaviour influenced in the short and medium-term by informative and warning ISA together, incentive ISA, and a combination of these in correlation with incentives of various size and type?

The answers to this question will be given for each of the two ISA trials separately, because the research design, the type of participating drivers, and the period lengths differ between the two trials.

Regarding PAYS, short term means 0-1.5 months after ISA activation, while medium-term means 3-4.5 months after ISA activation. The PAYS results regarding young drivers, aged 18-28, have a clear connection to the theories about how incentive works and the results of other ISA trials. Regarding short-term effects, it was found that the combination of *informative* and *incentive* ISA resulted in statistically significant less speeding and less speed variation than did either of them. Moreover, it was found that *incentive* without *informative* ISA worked significantly better than *informative* ISA without *incentive*. In ISA C short term was 0-2 months after ISA activation, while medium-term was 5-6 months after ISA activation. In ISA C, ISA resulted in a change in driving behaviour, which was somewhat similar to the effect of informative ISA in PAYS. These results hold good, in general, regarding 50 and 80 km roads, which is equivalent to 78% of the data studied. On 110 and especially on 130 km roads the pattern is more confounding. There might be three reasons for that: 1: the distance driven on these road types is short, 2: fewer drivers drove on these two road types, and 3: first results from PAYS and the *INFATI* trial showed that many drivers found 130 km per hour more than fast enough and therefore only limited effects of ISA could be expected here.

In the medium term the differences between the different ISA treatments became even more substantial. The effect of *informative* ISA differed markedly but in general decreased over time. Regarding *incentive* the effect appeared and remained although, in most cases, the effect of *combination* was significantly bigger than of *incentive* alone. In most cases the effects regarding *ISA C* decreased over time, but it should be noted that the smaller and less lasting effect might be due to the weaker incentive but maybe also due to another type of drivers. On the basis of this study, the connection between the size and type of incentive and the effect on driving behaviour cannot be clarified.

Hence, the overall answer is that informative and warning ISA combined with an economic incentive for avoiding speeding has a significant and lasting effect on driving behaviour. Also it is found that this combination works significantly better than do each of the parts of the ISA feedback (information together with warnings, and incentive) alone.

6.3 Future areas of research

Before ISA-related areas which need further research are presented, chalking the field of the research area is useful. In virtually all known ISA trials, there have been significant effects on driving behaviour due to ISA. The results of trials around the world are different but do suggest an almost unambiguous conclusion: ISA does improve road safety substantially due to reduced speeding. It is also found that the more intervening and hence efficient the ISA is, the less positive are drivers towards it. It is reflected by the market situation for ISA today. Only ISA which is easy to ignore or can be turned off is on the market at present, and only small scale. At first sight, this market situation does not fit well with the attitude to ISA, particularly with the speeding behaviour found in several studies. Most studies have found that there are problems regarding speeding, but only a minority of the respondents found that there are problems regarding their own driving behaviour. A reasonable interpretation is that most drivers asked found ISA useful, but in somebody else's car. Also, it has been found in many trials that the drivers who needed ISA the most, did not participate in the trials. Thus there was an underrepresentation of young drivers in most of the ISA trials. And moreover, in most trials in which that particular aspect was studied, the drivers were more positive towards ISA and speed limits than was the average driver. Hence only limited knowledge has been gained about any effect of ISA on these groups of drivers - groups of drivers among whom significantly improved road safety can be expected - if 1: they can be convinced that they have to drive with ISA, and 2: that the ISA system is made in such a way that it affects driving behaviour substantially and cannot just be avoided by turning up the radio, deactivating the system etc.

Future research should preferably focus on the challenges regarding a large-scale market introduction of ISA aimed at the groups of drivers who are not keen on this type of equipment. Possible options could be changes in the Road Traffic Act making it mandatory for selected groups of drivers to drive with ISA in shorter or longer periods. Three main areas of research can be identified in that connection.

How can the drivers who need ISA the most be convinced to have ISA installed in their car? We (the PAYS team) thought that a 30% discount on the insurance rate would make a large number of interested young drivers participate - also those who were normally rather negative towards speed reducing initiatives. As it turned out, it did not work, and the few young drivers who were convinced about the idea had a negative attitude to speeding. The question then is, what can convince the drivers to drive with ISA? Is a higher incentive than 30% needed? And should the incentive (or some of it) be given for participating only, like in the *Karmøy* trial? Should it be a requirement to drive with ISA the first year(s) of driving?

Also, having ISA installed in the cars does not necessarily mean that speeding will be avoided (unless ISA was mandatory intervening). The results of PAYS are convincing, but if the drivers were not voluntary, it is uncertain if a similar effect could be found. Should speeding be directly connected to the demerit points in the driving license?

Furthermore, it needs to be clarified if there are any approaches, which might result in lasting effects on driving behaviour - also after the removal of a particular ITS device. In most ISA trials where this aspect has been studied only a very limited, if any lasting effect was found. Is it a matter of time, of information, or what is needed to maintain the changed driving behaviour?

7 References

The list of references includes a number of references, which are not in English. I have filled in an English translation of the titles, in brackets after the original titles. Any errors in these translations are my responsibility only.

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Appendix 1: Information on selected ISA trials

Place/ Name	Time	Feedback	Activation level	Size	Research design	Data use	Additional information
Tilburg, Nether-lands	1999-2000	Dead throttle	Speed limit	20 cars + 1 bus. In total 120 drivers and 20 bus drivers	2 weeks baseline + 6 weeks with ISA	Amount of speeding Mean Speed Speed variation	
INFATI, Denmark	1999-2001	A display show-ing the speed limit+ audi-tory and visual feedback	Speed limit + 5 km/h	2*12 driv-ers	2 weeks baseline + 4 weeks with ISA	85 percentile Speed on maps 85 percentile Speed on road types (speed limits and area use)	
Borlänge, Sweden	2000-2001	A display show-ing the speed limit+ audi-tory and visual feedback. Later 10 cars were equipped with AAP	Speed limit + 2 km/h	400 cars	Baseline app. 1 month. 5-13 months with ISA activated. Two post periods with measurement on month after activation and one month be-fore termination of the ISA	PDA Mean Speed Speed variation Results both regarding selected mid-blocks and regarding all driving	
Lund, Sweden	2000-2001	AAP + display showing the speed limit	Speed limit + 2 km/h	284 cars	Baseline app. 1 month. 5-13 months with ISA activated	PDA Mean Speed Speed variation 85 percentile Speed Results both regarding selected mid-blocks and regarding all driving + driving behaviour studies	
Umeå, Sweden	2000-2001	Diode + audi-tory feedback (beep)	Speed limit + 2 km/h	3,879 vehicles	9-23 months	Point Speed measurements Road accidents statistics Conflict studies	No logging of driving data

Place/ Name	Time	Feedback	Activation level	Size	Research design	Data use	Additional information
Lidköbing, Sweden	2000-2001	AAP + display showing the speed limit/ auditory and visual feedback if speeding + display showing the speed limit	-	280 cars. 150 with Diode + auditory feedback (beep), 130 with AAP	Baseline app. 1 month. 5-17 months with ISA activated		No logging of driving data
Borlänge with in-centive, Sweden	2002	+ monthly feed-back on rewards	Speed limit + 2 km/h	95 drivers	1 months baseline 2 months with ISA Incentive was SEK 250 or 500 per month and was deducted depending on the amount and seriousness of speeding	PTA distributed in 3 severity classes.	
Ghent, Belgium	2002-2004	AAP + display showing the speed limit	Speed limit	34 cars + 3 buses. 62 drivers in total	Baseline (after period): 1 month ISA was activated in 9 months	Mean Speed 85 percentile speed Standard Deviation of Speed	The results were based on differences be-tween driving with AAP and driving with informative ISA only.
Belonitor, Nether-lands	2003-?	Warning ISA, FDW	Speed limit	65 rental cars	4 weeks baseline 16 weeks with ISA. 4 weeks post baseline Decreasing incentive during ISA period. Incentive points were turned to rewards	PDA	

Place/ Name	Time	Feedback	Activation level	Size	Research design	Data use	Additional information
PROS-PER/ Spain/ Hungary	2003-2004	AAP/visual and auditory feed-back (BEEP)	Speed limit	20 cars in Spain + 20 cars in Hungary	1 month baseline, 1 month with AAP, 1 month with BEEP, 1 month post baseline	Mean Speed 85 percentile speed Speed variation Results regarding selected spots only	
LAVIA, Paris, France	2003-2005	Warnings ap-pear in case of speeding Dead throttle with and without turn-off function	Speed limit	102 drivers, 20 cars	2 weeks of baseline 3*2 weeks with various feedback: advisory only, voluntary (dead throttle), mandatory (dead throttle)	Only small scale results are published to the knowledge of the author	
TAC Saf-ecar, Mel-bourne, Australia	2003-2005	Warning was given in a display, a loudspeaker and AAP. Warnings worked in two steps	Speed limit + 2 km/h	15 com-mercial cars + 8 as a control group	Per car: Baseline: 3,000 km ISA trial: 3,000 km, other studies and after period: 10,500 km	Mean Speed 85 Percentile Speed Maximum Speed per trip Median Speed Standard Devia-tion of Speed PTA Mean Travel Time	Also FDW and FDW in combination with ISA was studied
ISA UK, United Kingdom	2006	Advanced dead throttle+ infor-mative ISA	Speed limit+2% (start from -10%)	79 drivers	1 month baseline, 4 months with ISA, 1 month post baseline	Mean Speed 85 percentile Speed PDA Speed variation	
Karmøy, Norway	2007-2008	Removable PDA with informing and warning ISA. Data logging	Speed limit	50 young car owners	No baseline. Discount on the insurance rate regardless of the driving behaviour.	PDA (+5 and + 20 km/h)	Considerable proportion of the driving was without ISA feedback

Appendix 2: Statistical tests

Individual vs. system approach

To estimate any effect on driving behaviour on the basis of driving behaviour in more than one vehicle, there are basically two approaches: the *individual approach* and the *system approach*. With an *individual approach* it is assumed that each vehicle/driver contributes equally to the results, regardless of how much this particular individual contributes to the overall driving behaviour. With a *system approach* the amount of contribution from each driver depending for example on the distance driven is aggregated and the total effect is used to measure any effect. The *individual approach* allows the opportunity to take into account that each driver is unique and controls his/her own driving behaviour to some extent. Hence, actual behaviour can be compared with, for example, questionnaire-based answers given by the driver in question. Focus is consequently on the effect on the individual driver's driving behaviour and the importance of socio-economic characteristics in relation to the effects of ISA. On the other hand, drivers often drive very different distances, as shown by draft results from both ISA C and PAYS. Furthermore, a few drivers driving a long distance and speeding considerably were therefore given less weight. Hence the proportion of speeding in both baseline and in the ISA periods was underestimated. Due to the fact that no questionnaire results in relation to the individual driver are presented in this study and the distance driven being a key measure of traffic safety risk (Elvik et al. 2009), the *system approach* based on the distance driven has been selected for the estimations of the ISA-related effects on driving behaviour in the Danish ISA trials. Consequently, by applying the *system approach* the results can be used to illustrate the overall effects of implementing an ISA system on e.g. a national scale.

General conditions

The values used for the statistical tests regarding the effect of ISA are the distance driven (km) at the chosen speed compared to the speed limit under different conditions. Regardless of the test type applied, a p-value below 0.05 is considered statistically significant, while a p-value of 0.05-0.10 is regarded as tending to be statistically significant. The former is commonly used as critical value (Kreiner 1999). The latter might be questioned, however it seems reasonable to use it in relation to doubtful results. Also, this interval is suggested as useful in the Danish manual regarding road safety evaluations (Jørgensen 1981). The data were analysed for each defined road type. In order to document the effects of ISA in PAYS, two-dimensional statistical tests were carried out: 1: across different periods (baseline and three subsequent periods (*ISA1*, *ISA2*, and *ISA3*) for each ISA treatment, and 2: across each ISA treatment in each individual period. In total 6 times 4 per speed limit, and 2: across different treatments but in the same periods. In total 6 times 4 per speed limit. With four road types this amounts to 192 tests distributed over the various treatments and over different periods. The four treatments are: *control*, *incentive*, *informative*, and *combination*. Also, regarding PDA calculations are made of the total driving behaviour including driving on all the included road types, resulting in another 48 tests. So in total 240 tests of statistical significance regarding PDA were carried out regarding PAYS. Due to a much simpler research design in ISA C only 6 tests were made concerning results per speed limit. With four speed limits and the total driving behaviour including driving on all the included road types it resulted in another 30 tests regarding ISA C. Since the results are presented through frequency tables illustrating the number of kilometres driven within each defined speed category, the tests of statistical significance applied to the analysis of PDA are Chi^2 tests.

Results covering more than one road type hardly make sense regarding Mean Free Flow Speed (MFFS) and Free Flow Standard Deviation (FFSD) as described in Section 4.3. The number of statistically significant tests required for the statistical analyses of FFSD and MFSS are 216 for each type. Tests of statistical significance for FFSD and MFFS are *Levene's test of homogeneity of variance* and the *Wilcoxon Rank-Sum test*, respectively, as the FCD might be non-normal in some cases. A small number of paired t-tests are made in order to underpin the general discussion about the *time driven* vs. *distance driven* approach in measuring the effect of ISA, which will be expanded on in Section 4.3. When comparisons of PDA, MFSS, and FFSD between two periods or two treatments are presented, they will be denoted, for example, as *ISA1-ISA2* or *incentive-combination*. In these tests the null hypothesis is that there are no differences between driving behaviour, expressed through the PDA, MFSS, and FFSD, in the periods compared and across different treatments within the same period. The alternative hypothesis is that there is a difference. In the tests it is assumed that driving in each of the periods is independent of the other periods because it is carried out in another time and in many cases also in another locality. Therefore the independence requirement is assumed to have been met.

Chi^2 test

In the statistical analysis of PDA, the *Chi^2* test is applied. This test is used because it is not based on the assumption that data are normally distributed (Kreiner 1999). Moreover, even though it is a generic test, which might be less informative than more sophisticated statistical significance tests, still a large amount of data result in diminishing variations between results from a *Chi^2* test and from more advanced tests (Kreiner 1999). In total 240 bivariate tests were carried out. Driving data were distributed in two times two frequency tables. For each treatment in each period driving data was aggregated to two values: the distance driven (km) which was driven more slowly than or equal to the speed limit+ 5 km/h, and the distance driven which was driven faster than the speed limit+ 5 km/h. The *Chi^2* tests were entered in a spread sheet.

The Wilcoxon Rank-Sum test

The MFFS was tested for statistically significant differences by means of the *Wilcoxon Rank-Sum test*. This test was selected for yielding reliable test results, whether the data are normally distributed or not (Walpole et al. 2007). In a *Wilcoxon Rank-Sum test* the values of data are ranked in ascending order and transformed, as the rank of each speed observation is assigned to each of the speed observations. In case of identical observations the mean rank of all the identical observations is assigned for these observations. Then the means of these ranks are compared to test for statistically significant differences. Hence the *Wilcoxon Rank-Sum test* is based upon the assumption that if the means of the ranks differ significantly from each other, it can be assumed that the differences in the MFFS are statistically significant (Montgomery 2005). FCD which had been aggregated as shown below were simplified. Data were entered in a number of spread sheets so every single km driven was represented by the speed at which this km had been driven. This procedure was carried out for all different treatments and periods for each of the four road types. Subsequently, data were filled into the SPSS computer programme in which the statistical tests were carried out.

Levene's test of homogeneity of variance

To test if there are statistically significant differences between FFSD in each period and between each different treatment in the same period a *Levene's tests of homogeneity of variance* is applied. The test was used because the standard deviations (SD) have to be compared; SD being the square root of the variance. A *Levene´s test tests for homogeneity of variance* is applied as it provides robust results also when data are not normally distributed (Kreiner 1999). In total 216 tests of statistical significance were carried out. FCD had to be simplified to make the said Levene's tests of homogeneity of variance. The data used for the *Levene's test* are the same as for the *Wilcoxon Rank-Sum test*.

Paired t-test

A *paired t-test* was used to test the differences between a time driven and a distance driven approach. The analysis was performed in order to determine which type of data is best suited for estimating the effects of ISA, see Section 4.3. Regarding PDA in the two ISA trials, *TAC Safecar* and ISA C, this test type was used. A paired t-test is used on an individual level because the purpose is to test data rather than to measure effects of ISA. With data from 13 and 26 cars participating in *TAC Safecar* and ISA C, respectively, the results were 13 and 26 differences between this variable in the 'effect period' and the 'baseline period' for the two trials, respectively. Then a standard t-test was applied to test whether the theoretical mean of these differences was significantly different from zero. As for the above-mentioned tests of statistical significance a p-value below 0.05 is assessed as statistically significant, while a p-value of 0.05-0.10 is regarded as tending to be statistically significant. A t-test is useful in estimating the statistically significant differences between mean values (Kreiner 1999).

Considerations about the test results

Due to the fact that the numbers of data in the statistical tests regarding driving behaviour data in the Danish ISA trials are considerable, it has in general not been a problem to reach results of statistical significance - rather the opposite. Some might argue that all results that are statistically significant should be presented and discussed in detail. However, in this case the discussion has been limited to and focussed upon the most interesting and significant results.

Appendix 3: Included scientific articles

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Preliminary results from the Danish Intelligent Speed Adaptation Project Pay As You Speed

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Abstract: The driving behaviour of participants in the Danish Intelligent Speed Adaptation (ISA) project 'Pay as You Speed' (PAYS) is described. The project is the first ISA project based on Pay as You Drive principles. Thus, the ISA equipment both notifies the driver that he/she is speeding ('information') and applies penalty points which decrease the driver's chance of a potential 30% discount on the cost of his/her automobile insurance ('incentive'). The results presented are based on the first 38 of 180 participants. The key result is that the combination of 'information' and 'incentive' almost eliminated speeding on rural roads while significant reductions in speeding were found also for urban roads and to some extent motorways. On roads with speed limits of 50, 80 and 110 km/h the proportion of distance travelled when speeding was reduced significantly. No significant results were found for motorways with speed limits of 130 km/h. In a future paper the final results from 'PAYS' will be presented.

1 Introduction

In 2001 Europe's grim road accident statistics indicated more than 40 000 fatalities, which forced the European Commission to set a target of reducing the number of road fatalities in Europe by 50% by 2010 [1]. Nevertheless, in 2005, 41 000 people were killed and 1.7 million were severely injured on Europe's roads. To achieve the goal that was set, more has to be done to prevent accidents from occurring. Intelligent Speed Adaptation (ISA) and other Intelligent Transport Systems will certainly be a central tool for reaching this goal [2].

ISA is a general term for systems that compare the speed of a car with the speed limit at the car's location. In most new ISA systems, the geospatial position of a car is used to compare the car's current position and speed with a digital road map, which includes the local speed limits. If the speed limit is exceeded, the ISA equipment issues a response. There are various forms of response; it can consist of a visual and/or audible warning in real time, registration of the speed limit violation in an on-board car computer, resistance to further speeding built into the accelerator and speeding made impossible. The different ISA systems can be categorised as informative, advisory, recording or intervening systems [3].

In the last decade, many ISA projects in several European countries and in Australia have shown the potential of ISA. The large-scale Swedish trials in Borlänge, Lidköping, Lund and Umeå during the period 1999–2002 involved almost 5000 cars. One of the main results was an average speed reduction of 3–4 km/h [4].

The first ISA project in Denmark was with informative and advisory ISA and was called INFATI. It was conducted at Aalborg University from 1998 to 2001. The actual speed limit was shown on a display, while the advisory system had a female voice stating the speed limit and the sentence 'You are driving too fast' every 6 s if speeding. The project consisted of only 24 drivers tested for 6 weeks, but the results from INFATI were promising. A speed reduction of up to 5–6 km/h was reported. Compared with other ISA projects, the INFATI project took place in both urban and rural areas. The largest reduction in speed was found in the rural areas, where speed limit compliance was smaller [5]. The results are remarkable considering that the majority of severe accidents and fatalities happen in rural areas [6].

In the Australian TAC Safecar project, which was carried out from 2002 to 2004 in the Melbourne area, a reduction of up to 2.7 km/h was found for the 85th percentile speed. Moreover, speeding by more than 5 km/h was reduced by up to 57% [7].

Further, a recent Swedish ISA project carried out from 2003 to 2005 in Stockholm, Sweden, indicated some promising results. For a speed limit of 30 km/h, no reduction in speed was registered. On roads with speed limits of 50–110 km/h, a reduction of 1.1–2.0 km/h was reported. In general, driving speed was distributed closer to the speed limit when driving with ISA [8]. A field trial carried out in Belgium showed a reduction of up to 2.5 km/h for the 85th percentile speed [9]. Finally, ISA trials carried out in the UK [2] and the Netherlands [10] have shown promising results. In general, the ISA projects conducted to date have shown that ISA is effective in reducing speed and, in particular, on roads with high speed limits.

1.1 Pay As You Speed project

A fundamental hypothesis in many of the ISA projects carried out to date has been that motorists would like to comply with speed limits, but find that, in practice, complying with speed limits can be difficult in a modern, comfortable car. Therefore the purpose of ISA is to support the motorist in choosing the proper speed. The assumption is that speeding will be avoided, as drivers who receive such support will no longer speed. Many ISA experiments have shown support for the hypothesis; speed falls and the users say that they are pleased to have ISA in their vehicles. However, despite the general effectiveness of ISA and users' support of the system, there has not, until recently, been a breakthrough for ISA in the commercial market. There is much to indicate that more than goodwill is needed before drivers voluntarily invest in ISA. How can we reward drivers, who drive with ISA? In this project the effect of bonus on the insurance rate to ISA drivers is studied.

Therefore it has been desired to select a group for this study, which has been under-represented in most ISA projects. Other studies have also indicated that the drivers who need ISA the most are less willing to have it [11]. Young drivers are under-represented in most ISA projects [12]. Moreover, it is well known that young drivers aged 18–28 years have a high accident risk. They are less likely to adhere to speed limits and they are less experienced. In Denmark, statistical studies have shown that this group has up to seven times higher traffic accident risk than drivers in their parents' generation [13]. Finally, young car owners also pay a high insurance rate on their car. Hence, young car owners aged 18–28 years have been targeted to serve as participants in this study.

The young drivers' high accident risk and their resistance to voluntary ISA formed the overall hypotheses for the project: a speeding-dependant bonus on the insurance premium will get young car drivers to accept ISA in their car and such an ISA system will reduce their speeding. We call the principle Pay As You Speed (PAYS) with reference to the term Pay As You Drive which is often used about car insurance, where the premium is calculated depending upon vehicle usage, particularly distance travelled.

The PAYS project is based on experiences from the INFATI project and consists of three parts. The first part involved creating a digital speed map of 22 000 km of road covering the County of North Jutland in Denmark. The second part involved the development of Global Position System (GPS)-based ISA equipment, with high reliability. The third part involved recruitment of up to 300 car owners aged between 18 and 28 to take part in a 3 year study of which the first 6 months would be driven under special conditions to test the effectiveness of incentive and informative forms of ISA. For participating in the study, drivers were offered a 30% discount on their car insurance premiums. However, were the drivers to speed, then the amount of discount received would be reduced in accordance with the degree and length of the speeding.

After an initial 'baseline period' (no ISA), participants were assigned randomly into one of four ISA groups: 'incentive' only, 'information' only, 'combination' (i.e. incentive and information), and 'no treatment' (i.e. the 'control' group). The latter group continued as in the 'baseline period'. Participants' speeding performance during the treatment period was compared with their performance in the 'baseline period'. The results presented in this paper derive from 38 participants only and on data collected during the first 3 months of the project period. Hence, the results are preliminary. The low number of participants in this study is caused by a slower recruitment than expected.

The following three hypotheses guided the analyses presented in the current paper:

1. It is expected that 'incentive ISA' reduces the proportion of speeding and the speed variation.

2. It is expected that 'informative ISA' reduces the proportion of speeding and the speed variation.

3. It is also expected that the combination of 'incentive ISA' and 'informative ISA' is more efficient than each of them.

2 Methods

2.1 Equipment

The ISA1 equipment ['On Board Unit' (OBU)] used in the current project obtains the car's position from a GPS receiver. In the OBU, the position is matched to the speed map and the actual vehicle speed is compared with the speed limit of the location. The actual speed limit is shown on a display, which is positioned in front of the driver. It is shown when the ignition is turned on. If the car exceeds the speed limit by more than 5 km/h, the driver receives a verbal warning. The warning is repeated every 6 s until the speed is back below the speed limit +5 km/h. The third and subsequent warnings result in penalty points. The number of penalty points increases gradually, so a small violation results in fewer penalty points than does a serious and dangerous violation. The size of the speed violation which activates the ISA is selected because most Danish road users drive close to the speed limit, but not necessarily below it. So, if we had made a system that reacted as soon as the speed limit was met, the participants would have felt pressure too often from the cars driving behind them. Also, the Danish rules for speeding fines incorporate these principles. No fine is received if speeding is less than 10% of the limit +3 km/h.

Once every second the OBU generates a GPS-based position including the speed limit, actual speed, position and quality of the map matching. This is called the 'one second log'. These data are transferred during the night via general packet radio service (GPRS) to a database for storage for research purpose, while the penalty points are reported to the participants on a webpage immediately after the end of each trip.

Every 6 months, penalty points are calculated for each participant. If the participant has earned no penalty points, the participant receives a 30% discount on his/her car insurance rates. Each penalty point deducts 7 Euro cents from this discount. No matter what the number of penalty points, the insurance rate can never be higher than it was before the driver participated in the ISA project. For more information about the project design, see Lahrmann *et al.* [14].

2.2 Participants

In this article, the participants' performance in the 'baseline period' is compared with the next 1.5 months (subsequently named 'ISA period'). In all 38 participants, 11 women and 27 men, aged 18–28 years, were included in this study. The 38 participants were the first of 180, so the results are preliminary. There are nine participants in the 'information' group, ten in the 'incentive' group, ten in the 'combination' group and nine in the 'control' group. These four groups are described in the next section.

2.3 Research design

In PAYS, the participants have the equipment in their cars for 3 years in total. However, to determine the effect of the equipment, a 1.5 month 'baseline period' in the initial project period is recorded. During this time, the participants drive with the display and the voice message switched off, so their 'normal' driving is recorded. In the next 4.5 months the participants are randomly assigned to one of four different groups (as shown in Table 1).

By comparing the driving performance in these four groups with driving during the 'baseline period', the effect of 'incentive', 'information', the 'combination' of these and the 'control' group can be measured. During the remaining 2.5 years, all the participants drive in the 'combination' mode. Comparisons between the four groups in the 'ISA period' are based on differences between the 'baseline' and 'ISA period' for each person.

2.4 Procedures

2.4.1 Data: This study is based on the 'one second log'. Data are recalculated, so it is suitable to do mileage-based studies. Effect from ISA in the first 1.5 months of the 'ISA period' will be compared with the driving in the 'baseline period'. In these 3 months, the 38 participants drove approximately 158 000 km in total, the majority of which was distributed across the following road types:

- Roads with a 50 km/h speed limit, which is the normal speed limit in urban areas (subsequently named '50 km roads' etc.),

- Roads with an 80 km/h speed limit, which is the normal speed limit in rural areas and

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Table 1 Four groups

		Incentive	
		−	+
information	−	control group: the participant receives neither information nor warnings or penalty points and continues like in the first one and a half months	incentive group: the display and the voice message are switched off and no information or warnings are given. The participant gets penalty points if speeding
	+	information group: the display and the voice message are connected and information and warnings are given. Speeding gives no penalty points	combination group: the participant receives information and warnings and gets penalty points if speeding

- Roads with a 110/130 km/h speed limit, which are the normal speed limits on motorways.

In all, 87% of the 158 000 km were driven on these roads, and hence the following results are based on mileage on roads with these speed limits. The remaining 13% mileage is not analysed further, since the number of kilometres on roads with the remaining speed limits is low and the results might be too uncertain.

The participants' behaviour is registered by 12 million GPS positions in total. This amount of data corresponds to approximately 1 h of driving per participant each day.

2.4.2 Analysing data: All results concerning speeding are based on mileage and not the time span. Time used is primarily useful when average speed and travel time are studied. When studying speeding, the use of time can result in bias, since a large violation of the speed limit will be underestimated compared with a minor one [9].

Because ISA gives warnings and any penalty points if the speed limit is exceeded by more than 5 km/h, the proportion of distance travelled above this speed is compared. Moreover, research has shown that the amount of speed variation influences the accident rate. The more the variation of speed the more are the accidents [15]. A reduced speed variation therefore indicates that the ISA equipment can reduce the number of accidents more than just related to the reduction of speed. To avoid blurring data and to avoid bias from congestion and idling, these results are based on the mileage where speed is higher than the speed limit minus a fixed proportion of kilometres per hour. On 50 and 80 km roads, it is −15 km/h; on 110 km roads it is −20 km/h and on 130 km roads it is −30 km/h. For example, for roads with a 50 km/h speed limit all mileage which is carried out with more than 35 km/h is included. These outcomes are here denoted as 'mean free flow speed' (MFFS; see Table 2).

This definition of free flow is not without controversy. We have contacted many scientists studying ISA-related subjects via the International Working Group on Speed Control (IWGOSC) mailing list. IWGOSC is a world-wide group of experts regarding ISA and related objectives. Some define free flow as all speeds above 15 km/h, whereas others suggest that free flow is all data when speed is above 50 km/h on motorways. In the Australian TAC SafeCar Project, the cars were equipped with a 'following distance warning' (FDW) system and hence they could sort out data if the vehicle in front was closer than 3 s [7]. A fourth suggestion was to remove all mileage during rush hours. However, our cars are not equipped with FDW and if we remove all mileage during rush hours, the amount of data collected will be low and hence too uncertain.

To calculate MFFS the average speed for all speed included as mentioned above is used. This definition of MFFS is a trade-off between two considerations. 1) Because of the fact that more the data, all things being equally result in more reliable results, as much data as possible are required. 2) Driving data from speeds far less the speed limit are of no relevance when

Table 2 Speeds for each speed limit, which is included in MFFS

Speed limit	50 km/h	80 km/h	110 km/h	130 km/h
Mean free flow speed	>35 km/h	>65 km/h	>90 km/h	>100 km/h

measuring ISA based on average speeds and should be avoided. Therefore we decided to use the above-mentioned limits of speed when defining MFFS.

2.4.3 Statistical analyses: To study the effects of 'incentive' and 'information' on the proportion of distance travelled with speeding above 5 km/h, for each speed limit we examine the difference between this variable in the 'ISA period' and the 'baseline period' (Section 3.1). Some participants did not attain any mileage in some of the speed limit classes. Hence, for some speed limits, the number of observed differences is <38.

Up to 38 differences are divided into four groups corresponding to the four combinations of incentive and information in the 'ISA period'. Let $i = 0,1$ correspond to no incentive or incentive and $j = 0,1$ to no information or information. The 'control' group then, for example, corresponds to $i = 0$ and $j = 0$. For the difference d_{ijk} for the kth person in the ijth group, we employ a two-way analysis of variance model

$$d_{ijk} = \begin{cases} m + e_{ijk}, & i = 0, j = 0 \\ m + a + e_{ijk}, & i = 1, j = 0 \\ m + b + e_{ijk}, & i = 0, j = 1 \\ m + a + b + c + e_{ijk}, & i = 1, j = 1 \end{cases}$$

In this formula, m is the mean difference for the 'control' group, e_{ijk} a normally distributed noise term and c an interaction parameter. If c is zero, the effects of 'incentive' and 'information' are additive and given by a and b, respectively. That is, in the absence of an interaction the expected difference between the 'combination' and the 'control' groups is $a + b$. A priori, one might expect $m = 0$.

In some cases the assumption of normally distributed noise was violated by the presence of outlying observations. To study the influence of such observations, we also did analyses excluding these observations but obtained qualitatively same results regarding the significance of model terms.

In addition to the proportion of distance travelled with speeding above 5 km/h, we consider MFFS and the standard deviation of 'free flow speed' computed as follows. For each person the MFFS is obtained by weighting each MFFS value with the proportion of the mileage travelled at this speed. Similarly, we compute a mean squared deviation (FFSD) for each person by weighting the squared distances between the MFFS values and the MFFS with the proportions of mileages for the speed values. The standard deviation FFSD is the square root of the mean-squared deviations.

The statistical analyses for MFFS and FFSD proceed exactly as for the proportion of mileage with speeding using a two-way analysis of variance for person-specific differences concerning these variables.

3 Results

3.1 Proportion of distance travelled while speeding

Table 3 shows the proportion of distance travelled at a speed exceeding the speed limit by more than 5 km/h in the four groups 'incentive', 'information', 'combination' and 'control' in the 'baseline' and 'ISA periods'.

It appears that the largest effect of ISA is found on rural roads with a speed limit of 80 km/h and to some extent on motorways with a speed limit of 110 km/h and on urban 50 km roads. As mentioned earlier, experience from the INFATI project showed that people have a higher acceptance of urban speed limits than rural, thus, the greater effect on 80 and 110 km roads can be explained. Also, questionnaires completed by young Danish automobile owners have shown that they have the lowest acceptance of speed limits of 80 km/h and a higher acceptance of the speed limits on both urban roads and partly on motorways [12]. Furthermore, it is likely that a large proportion of drivers consider 130 km/h to be fast enough. The differences between the four groups in the baseline period may be due to random variation since the results are based on a short time span and a small number of persons.

When comparing the four modes, it appears that the effect of 'incentive' in this first phase of the trial is less than from 'information', with a reduction in speeding by 4% on 50 km roads and 5% on 80 km roads. On 110 km roads, the reduction is 9% and on 130 km roads it is 3%. For participants receiving 'information' without 'incentive', the reductions are 5, 14, 18 and 1% for the four road types. When given both 'incentive' and 'information', the results are even better on 50 and 80 km roads: 11, 26, 14 and 4% for 50, 80, 110 and 130 km roads, respectively. For participants in the 'control' group the reductions is 2 and 3% for the 50 and 130 km roads, respectively, whereas increases of 5 and 16% are recorded on 80 and 110 km roads. This increased proportion of distance travelled with speeding above 5 km/h for the 'control' group will be discussed later. However, a similar but not significant trend is also found in the Australian TAC Safecar project [7].

To study more incisively the effects of incentive and information, two-way analyses of variances were fitted to person-specific differences between the proportion of

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Table 3 Proportion of distance travelled exceeding the speed limit by more than 5 km/h

		Speed limit							
		50 km/h		80 km/h		110 km/h		130 km/h	
		%	Change, %	%	Change, %	%	Change, %	%	Change, %
incentive	baseline	9	−4	19	−4	23	−9	7	−3
	ISA	5		15		14		4	
information	baseline	8	−5	18	−14	24	−18	2	−1
	ISA	3		4		5		1	
combination	baseline	13	−11	29	−26	16	−14	4	−4
	ISA	2		2		2		0	
control	baseline	16	−2	29	5	14	16	7	−3
	ISA	15		34		30		4	

distance travelled with speeding above 5 km/h in the 'baseline period' and the 'ISA period' (Section 2.4.3). For all speed limits, the interaction terms were not significant, so that the effects of 'incentive' and 'information' are additive. Table 4 includes the estimated effects *a* and *b* of 'incentive' and 'information' along with *P*-values (in parentheses) for the significance of these effects. Also the estimated mean difference *m* for the 'control' group is given.

The estimated effects of 'information' are in general a bit bigger than the estimated effects of 'incentive', indicating that 'information' is the most important factor for reducing speed. The effect of 'information' is significant at the 5% significance level except for 130 km roads, whereas 'incentive' is significant only for 80 and 110 km roads. Since the effects of 'incentive' and 'information' both lead to reduced speeding, the 'combination' of these effects is significant except for 130 km roads. One should expect a zero mean difference *m* between the 'ISA' and the 'baseline period' for the 'control' group. This parameter is, however, significantly different from zero for 80 km/h roads where the *P*-value, 3.7%, is just below the 5% significance level.

3.2 Speed variation and MFFS

Table 5 shows MFFS and free flow speed standard deviation FFSD (Section 3.3) obtained by merging the data for all the persons within each of the groups. Hence the proportion of distance travelled used to calculate the MFFS and FFSD values are those given in Figs. 1–4.

On 50 km roads, only minor changes in MFFS are found for the 'incentive' and 'information' groups. The effect on 80 km roads is also limited for the 'incentive' group and slightly larger with 2.5 km/h for the 'information' group. For the 'combination' group, a reduction by 2.8 and 5.4 km/h, respectively, on 50 and 80 km roads is observed, whereas the 'control' group hardly changes on urban 50 km roads and increases the speed by 2.2 km/h on rural 80 km roads. On 110 km roads, a small reduction is observed for the 'incentive' group and a larger reduction, 3.1 km/h, for the 'information' group. The 'combination' group barely changes, whereas a smaller increase of 2.3 km/h is observed for the 'control' group. On 130 km roads, no clear effect is found and the changes here are probably based on random behaviour.

Table 4 Estimated effects of 'information' and 'incentive' on proportion of distance travelled with speeding more than 5 km/h and estimated mean difference for 'control' group

	Speed limit			
	50 km/h	80 km/h	110 km/h	130 km/h
incentive	−4.2 (0.053)	−12.9 (0.006)	−13.1 (0.013)	−0.6 (0.971)
information	−6.0 (0.007)	−16.7 (0.001)	−14.7 (0.006)	−2.2 (0.207)
control	1.8 (0.333)	8.47 (0.037)	7.9 (0.095)	0.6 (0.715)

Table 5 MFFS (km/h) and FFSD for 'baseline' and 'ISA' for the four groups

		Speed limit							
		50 km/h		80 km/h		110 km/h		130 km/h	
		MFFS	FFSD	MFFS	FFSD	MFFS	FFSD	MFFS	FFSD
incentive	baseline	47.1	7.5	80.3	8.4	111.0	9.0	121.1	10.6
	ISA	46.4	7.0	79.4	8.3	109.7	7.5	122.0	8.9
information	baseline	47.1	7.3	81.1	10.1	110.3	8.9	120.4	7.1
	ISA	46.3	5.9	78.6	6.3	107.2	6.1	120.7	7.3
combination	baseline	49.1	9.0	83.4	10.7	107.4	9.0	116.9	10.1
	ISA	46.3	6.1	78.0	5.3	107.2	6.4	117.2	8.9
control	baseline	49.9	9.0	83.6	10.3	110.0	7.8	119.9	10.5
	ISA	49.7	8.6	85.9	12.4	112.3	9.3	121.8	8.2

According to the two-way analysis of variance for person-specific MFFS differences, there is no interaction effect between 'incentive' and 'information'. The estimated effects of 'incentive' and 'information' on MFFS and the mean difference for the 'control' group are shown in Table 6, with *P*-values in parentheses. The estimated effects of 'information' were again a bit bigger than those for 'incentive' and all the effects were significantly different from zero at the 5% significance level except for 130 km roads. As in Section 3.1, the mean difference for the 'control' group was somewhat counter intuitively significantly different from zero for 80 km/h roads.

Speed variation FFSD indicates the range of speed on a road. If it is small, it means that most of the traffic is driving at almost similar speeds. On 50 km roads, only larger reductions for standard deviation are found for the 'information' and the 'combination' groups, with 1.4 and 2.9 km/h, respectively. On 80 km roads, the effect is even bigger for the two groups, with 3.8 and 5.4 km/h, respectively, whereas an increased FFSD is found for the 'control' group. On 110 km roads the same trend is found even if the difference between the 'information' and the 'combination' is limited. On 130 km roads no clear and obvious changes are found.

Turning to the two-way analysis of variance, the interaction effect for 'information' and 'incentive' was insignificant also for FFSD. Table 7 shows estimated effects of 'information' and 'incentive' and estimated mean difference in the 'control' group as well as *P*-values in parentheses. The estimated effects of 'information' and 'incentive' are all negative, corresponding to reduced FFSD. However, the 'incentive' effects were only significant at the 5% level for 80 km roads, whereas the 'information' effect is significant both for 50 and 80 km roads. Again the mean difference for the 'control' group is significantly different from zero only for 80 km/h roads.

Figs. 1–4 show the proportions of 'free flow speed' distance travelled at each speed value. On 50 km roads (Fig. 1), the proportion of distance travelled above the speed limit +5 km/h is minimal for the 'combination' but barely bigger for the 'incentive' and the 'information' groups. For the 'control' group, the proportion is higher. The variation differs only slightly between the 'information' and 'combination' groups with an FFSD of 5.9 and 6.1 km/h, respectively. The FFSD is slightly bigger for the 'incentive' group and is biggest for the 'control' group. The lower variation for the 'information' group and the 'combination' groups is mostly caused by high speeds, which have disappeared.

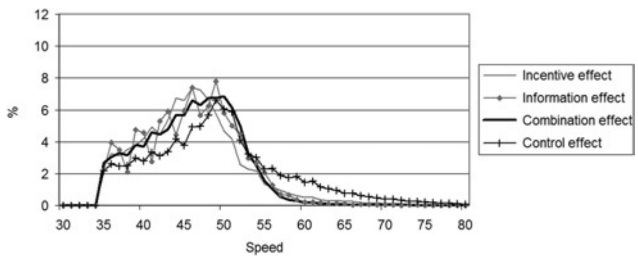

Figure 1 *Speed distribution on 50 km roads in the 'ISA period' for the four groups based on MFFS*

The speed distributions for 80 km roads are shown in Fig. 2. The variation differs somewhat between the 'information' and 'combination' groups with an FFSD of 6.3 and 5.3 km/h, respectively. The FFSD is somewhat bigger for the 'incentive' group and biggest for the 'control' group, with an FFSD of 8.3 and

12.4 km/h, respectively, and hence the speed distribution for the 'control' group is more than twice as big as for the 'combination' group. The reduced speed variation on 80 km roads for the 'combination' and to some extent for the 'information' group is also caused by infinitesimal speeding. It seems also that there is a reduction in the amount of low speeds. No explanation is found for this, but it might be because the participants are using the ISA equipment as a kind of semi-automated cruise control. This is also the suggestion in the Australian and the Swedish ISA projects, where the same trend was found [7, 16].

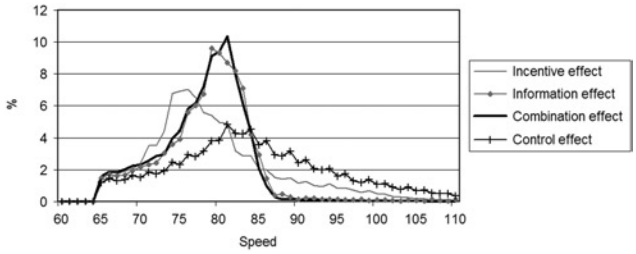

Figure 2 *Speed distribution on 80 km roads in the 'ISA period' for the four groups based on MFFS*

The same trend is found for the 110 km roads. The variation differs a bit between 'information' and 'combination', with an FFSD of 6.1 and 6.4 km/h, respectively. The FFSD is somewhat bigger for the 'incentive' group and biggest for the 'control' group, with an FFSD of 7.5 and 9.3 km/h, respectively (Fig. 3).

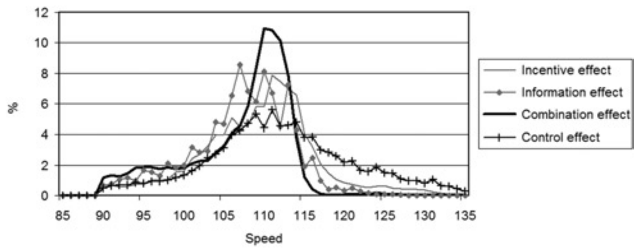

Figure 3 *Speed distribution on 110 km roads in the 'ISA period' for the four groups based on MFFS*

On 130 km roads the results are not as clear. The variations for the 'incentive' and 'combination' groups are equal with an FFSD of 8.9 km/h, whereas the 'free flow standard deviation' for the 'information' group is lower (7.3 km/h) and the 'control' group is in between with 8.2 km/h (Fig. 4).

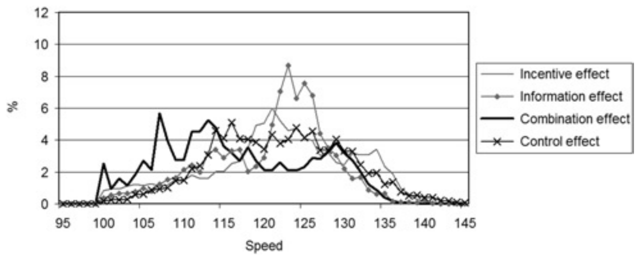

Figure 4 *Speed distribution on 130 km roads in the 'ISA period' for the four groups based on MFFS*

The study of the speed variation curves and the 'free flow standard deviation' for the four groups shows that the combination of 'information' and 'incentive' gives a

Table 6 Estimated effects of information and incentive on MFFS and estimated mean difference for 'control' group

	Speed limit			
	50 km/h	80 km/h	110 km/h	130 km/h
incentive	−1.2 (0.029)	−3.6 (0.007)	−2.9 (0.041)	−0.1 (0.933)
information	−1.7 (0.000)	−4.2 (0.002)	−3.3 (0.019)	−0.5 (0.701)
control	0.7 (0.156)	3.2 (0.006)	2.1 (0.107)	1.5 (0.249)

Table 7 Estimated effects of information and incentive on FFSD and estimated mean difference for 'control' group

	Speed limit			
	50 km/h	80 km/h	110 km/h	130 km/h
incentive	−0.7 (0.086)	−3.9 (0.003)	−1.2 (0.350)	0.8 (0.347)
information	−1.3 (0.002)	−3.1 (0.015)	−1.6 (0.199)	−0.5 (0.529)
control	0.4 (0.234)	3.2 (0.005)	0.7 (0.563)	−0.4 (0.635)

smaller speed variation on 80 km roads than each of them separately – a decrease which, with reference to the literature, will improve traffic safety for drivers [15]. On 50 and 110 km roads, 'information' seems to have almost the same effect as the 'combination' and no clear effect from ISA is found on 130 km roads.

4 Conclusion and discussion

The aim of the study presented in this paper was to test whether a form of ISA based on Pay as You Drive principles is effective in reducing speed in the Danish County of North Jutland. Although 180 participants, in total, are taking part in the study, the results given in the current paper are based on the data of 38 participants only, who are aged 18–28 years old. Therefore the results presented in the current paper should be treated as a preliminary.

To determine the effectiveness of the ISA equipment, participants drove a vehicle for 1.5 months in the absence of ISA ('baseline period') while certain information regarding their driving performance was recorded. Performance in the 'baseline period' was compared with drivers' performance in the next 1.5 months. This period was called the 'ISA period'. In the 'ISA period', participants were exposed randomly to one of four different ISA conditions: 'information' only, 'incentive' only, 'combination' (information and incentive) or no treatment ('control' group). By comparing the driving behaviour of the four groups with their driving during the 'baseline period', the effects of the 'incentive', the 'information' and the 'combined' forms of the ISA system on driving behaviour could be determined.

The key findings were as follows. The effect, relative to the baseline, of the 'incentive' ISA system was less than that of the 'information' ISA system. With the 'incentive' system, a reduction of 4% on 50 km roads and of 5% on 80 km roads was found in the proportion of distance travelled by more than 5 km/h above the speed limit. On 110 km roads, the reduction was 9% and on 130 km roads it was 3%. With respect to the 'information' system, the reductions on 50, 80, 110 and 130 km roads were 5, 14, 18 and 1%, respectively. The only results to attain statistical significance for the 'incentive' system were those for the 80 and 110 km roads, whereas for the 'information' system, the results were significant for the 50 km roads as well.

On the 50 km roads, the preliminary data showed that, relative to the baseline, the proportion of distance travelled by more than 5 km/h above the speed limit when driving in the 'combination' mode dropped from 13 to 2%, whereas on rural 80 km roads a reduction from 29 to 2% was revealed. On 110 km motorways, a reduction from 16 to 2% was found. All reported results regarding the 'combination' ISA condition were statistically significant. Moreover, the 'incentive' and 'informative' ISA forms in 'combination' resulted in greater reductions in speeding than did either the 'incentive' and 'informative' forms of ISA individually. For participants in the 'control' group the reductions in the proportion of distance travelled by more than 5 km/h above the speed limit were 2 and 3% for the 50 and 130 km roads, respectively, while increases of 5 and 16% were recorded on 80 and 110 km roads. Only the result for the 80 km roads was found to be statistically significant.

In addition, the participants who received the 'combination' of 'information' and 'incentive' showed a reduction, relative to the baseline, in their 'MFFS' by 2.8 km/h on urban 50 km roads and 5.4 km/h on rural 80 km roads. On motorways, however, the effect was infinitesimal with respect to 'MFFS'.

The results seem quite clear and substantial for the 'combination' group. Both the 'incentive' and the 'information' groups had minor, but also promising results. The participants in the 'control' group showed, for some speed zones, an increase in their general speed during the 'ISA period' relative to the baseline. Other than random variance, the most likely explanation for this result is that the 'control' group in the beginning was aware of the equipment, and that this awareness decreased as time passed. If this tendency were found to last throughout the remaining 4.5 months of the study, then it can be concluded that the effect from the ISA-equipment, and hence the recorded results, are even more substantial than noted.

One might expect that the effect from the 'incentive' form of ISA would be larger than that from the 'information' form of ISA since the driver might, over time, become used to the warnings but not the insurance penalty. Nevertheless, this pattern might change later in the project period once the drivers in the 'incentive' group have had more exposure to the system and therefore have become more aware of the impact, potential or real, of speeding on their insurance premium.

These preliminary results from the first ISA project based on Pay as You Drive principles are very promising. Consistent with the first two hypotheses, these early results show that both 'information' and, to some extent, economic 'incentive' forms of ISA are effective in reducing participants' speeding. In line with the third hypothesis, the results also show that the 'combination' of these modes gives the largest

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reduction in speeding and that the effect from incentive and 'information' are additive. Besides this, speeding by more than 5 km/h is almost eliminated among drivers in the 'combination' group. Moreover, it seems that the PAYS concept has the greatest effect on 80 km roads, where speeding is almost eliminated. Finally, the speed variation on rural 80 km roads is reduced by approximately one half.

During the remaining phases of the study, the focus will be on a number of topics. More research will be carried out based on all participants' behaviour and hence more reliable results may occur. Besides this, it will be studied whether the effect of 'incentive' ISA increases with time and whether the effect of 'information' ISA decreases over time. The long-term effect of ISA will be studied because after 6 months, that is, when all participants are driving in the 'combination mode', it will be determined if the results continue to be as positive as the preliminary ones or whether any disregards to the ISA system occur. Finally, any changes in attitude to traffic-related issues in general and more specific speeding among the participants will be studied, to recognise if the effect on the participants' attitude remains over time. The latter is based on two questionnaires sent to each participant, one in the initial 'baseline period' and the other approximately 5 months later.

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Spar på Farten - opbygning og vedligeholdelse af hastighedskortet

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Abstract

Spar på Farten er et Nordjysk INFATI projekt (Intelligent FartTilpasning). Projektet er baseret på et princip om, at i jo mindre grad hastighedsgrænsen overskrides, jo mere sparer den enkelte forsøgsdeltager på sin bilforsikring. Når overskridelse af hastighedsgrænsen skal gøres op i penge, er det meget vigtigt, at overskridelserne er baseret på korrekte hastighedsgrænser. Derfor er vedligeholdelse af projektets hastighedskort af vital betydning. Det udviklede hastighedskort er planlagt til at være delt mellem kommunerne i Nordjylland og projektet. På trods af det, har det vist sig, at opdateringerne fra kommunerne har været begrænsede og at kun 46 % af kommunerne har indrapporteret ændringer til hastighedskortet. Dermed har kommunernes involvering i projektet ikke været en garanti for et opdateret hastighedskort.

Keywords

Dansk: Intelligente Transportsystemer, Intelligent Farttilpasning, digitale hastighedskort, vedligeholdelse, map matching

English: Intelligent Transport Systems, Intelligent Speed Adaptation, digital speed map, maintenance, map matching

Baggrund

Forskningsprojektet *Spar på Farten* er en videreførelse af *INFATI*-projektet (Intelligent Speed Adaptation, forkortet til ISA på engelsk), som Trafikforskningsgruppen ved Institut for Samfundsudvikling og Planlægning på Aalborg Universitet gennemførte i 1998-2001. Projektet *Spar på Farten* er et forsøg i det gamle Nordjyllands Amt og målgruppen er primært unge førere, dvs. aldersgruppen 18-28 år. Det er projektets overordnede formål at afprøve, om økonomiske incitamenter i form af præmienedsættelser på bilforsikringen ved overholdelse af hastighedsgrænserne kan tilskynde målgruppen til at køre langsommere og dermed reducere gruppens meget høje uheldsfrekvens.

Forskningsprojektet begyndte i 2004 og vil fortsætte indtil 2010. De første 2½ år er nu overstået og projektets hardware og software er udviklet, og de første deltagere har kørt med udstyret i godt ét år. I de næste tre år skal op til ca. 300 forsøgspersoner ud at køre med udstyret. I den periode indsamles data og de vil - sammen med hele projektet - løbende blive evalueret.

Spar på Farten er et samarbejde mellem Aalborg Universitet, Nordjyllands Amt, det private elektronikfirma M-Tech samt forsikringsselskabet Topdanmark. Endvidere har Færdselsstyrelsen under Transport- og Energiministeriet bidraget med væsentlige økonomiske tilskud til projektet.

En kort projektpræsentation

Udstyret

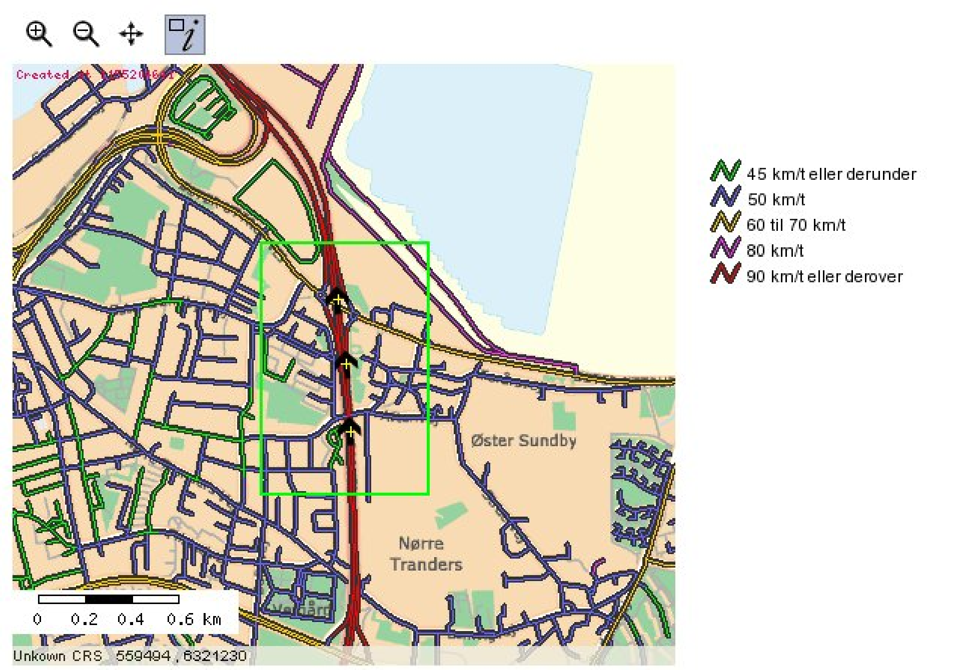
For at minde føreren af bilen om en eventuel hastighedsoverskridelse, monteres der i bilen tre mindre enheder [1]:

- En lille computer, der indeholder en GPS-modtager, en GSM-telefon, et digitalt vejkort med hastighedsgrænser i hele Nordjylland samt software, der kan guide føreren
- Et display med en lille højttaler
- En GPS-antenne

Figur 1. Display med højttaler.

GPS-modtageren fortæller hvert sekund computeren, hvor bilen er. Computeren beregner hvilken vej bilen befinder sig på (map matching), og hvilken hastighedsgrænse, vejen har. I displayet vises hastighedsgrænsen. Se figur 1. Overskrides grænsen med mere end 5 km/t, vil en kvindestemme hver 6. sekund minde føreren om overskridelsen, og føreren vil få strafpoint fra og med det 3. strafpoint. Hvor mange strafpoint, advarslen koster, gradueres efter, hvor mange procent overskridelsen er på. I den nederste linie til venstre i displayet ses det totale antal strafpoint, der er registreret i indeværende 6 måneders periode. Til højre i nederste linie ses det antal strafpoint, der er registreret på den aktuelle tur. Umiddelbart efter en afsluttet tur indrapporteres overskridelser (og uregelmæssigheder) til en server. Kort efter kan deltageren gå på Nettet og orientere sig om sine overskridelser. Deltageren har mulighed for at påklage evt. forkerte strafpoint via projektets hotline.

Figur 2 viser et screen dump fra webserveren, hvor tre overskridelser er markeret på motorvejen i nordgående retning i Aalborg. Yderligere information vedrørende overskridelserne ses under kortet.



Hastighedsoverskridelser

Hastighedsgrænse	Bilens Hastighed	Antal point	Dato og tid	Overskridelse nr.	Tur nr.
90	103	1	13.07.06 kl. 17:45:31	73	46
90	102	1	13.07.06 kl. 17:45:41	74	46
90	102	1	13.07.06 kl. 17:45:51	75	46

Figur 2. Screen dump fra webserveren.

De første testkørere fik installeret udstyret i maj 2006. Siden er udstyret installeret løbende i takt med rekrutteringen. I juli 2007 kørte ca. 100 biler med udstyret.

Selve forsøget

I *Spar på Farten* kører deltagerne med udstyret i i alt tre år. For at måle effekten af udstyret, køres de første 1½ måned som en førperiode, hvor højttaler og display er slået fra, mens kørselsadfærden registreres, så deltagernes "normale" adfærd i trafikken registreres. I de næste 4½ måned fordeles deltagerne tilfældigt i fire grupper, hvor der køres under forskellige vilkår. Vilkårene i de fire grupper fremgår af figur 3.

<table>
<tr><td></td><td></td><td colspan="2">Incitament</td></tr>
<tr><td></td><td></td><td>-</td><td>+</td></tr>
<tr><td rowspan="2">Information</td><td>-</td><td>Kontrolgruppe
Deltagerne modtager hverken information, advarsler eller strafpoint og fortsætter som i de første 1½ måneder.</td><td>Incitamentgruppe
Displayet og højttaleren er slået fra og der gives hverken information eller advarsler. Deltageren modtager dog strafpoint, hvis der køres for stærkt.</td></tr>
<tr><td>+</td><td>Informationgruppe
Displayet og højttaleren er slået til og information samt advarsler gives. Overskridelse af hastighedsgrænsen giver ingen strafpoint.</td><td>Kombinationgruppe
Deltageren modtager både information og advarsler og modtager strafpoint, hvis der køres for stærkt.</td></tr>
</table>

Figur 3. De fire grupper.

Ved at sammenligne kørselsadfærden i de fire grupper med adfærden i førperioden kan effekten af henholdsvis incitament, information og kombinationen af disse måles. I de resterende 2 ½ år kører alle deltagerne som i kombinationsgruppen. De foreløbige resultater skal ikke uddybes nærmere her, men det kan kort nævnes, at udstyret stort set eliminerer kørsel med en hastighedsoverskridelse større end fem km/t på veje med en hastighedsgrænse på 80 km/t. For flere resultater se i øvrigt Agerholm et al. 2007 [1].

På grund af projektets udformning er et præcist og opdateret hastighedskort meget vigtigt. Hvis der er fejl, modtager deltagerne forkerte advarsler og endnu værre, måske får de ikke det økonomiske incitament, som de er berettet til.

Opbygning af hastighedskortet

Et hastighedskort kunne i sin simpleste form se ud som et vejmidtetema med en hastighed som attributdata. Det vil i langt de fleste tilfælde være ganske fornuftigt. Men der vil dog være enkelte steder, hvor to hastigheder pr. vejstrækning vil være nødvendig. Enkelte steder, f.eks. før nogle kryds, er der forskellige hastigheder i vejens to retninger, idet hastigheden her nedsættes et stykke før krydset for igen at ophæves straks efter krydset. Det er altså nødvendigt med to hastigheder pr. vejstrækning. Desuden er der forskellige hastighedsgrænser afhængigt af trafikanttype såsom lastbiler og biler med trailere. Endvidere er der også tidsmæssige ændrede hastighedsgrænser såsom i forbindelse med vejarbejde, samt i nogle sommerhusområder, hvor hastighedsgrænsen er sænket i sommerperioden.

For at få et pålideligt hastighedskort, hvor opdateringsprocedurerne og kommunikationen af opdateringerne bliver overkommelige, blev det besluttet, at hastighedskortet skal indeholde:

- Vejmidter (Northing og Easting koordinater)
- To hastigheder (en hver vej)
- Vejkode

Her tages ikke højde for vejarbejder samt sæsonændringer af hastighedsgrænsen. Se figur 4 for et eksempel på hvad hastighedskortet skal indeholde.

N-koordinat	E-koordinat	Hast. med	Hast. mod	Vejkode
6320151.29	553160.08	15	15	0
6320173.65	553150.59	15	15	0
6351293.70	615888.62	50	30	8250219
6351294.05	615906.44	50	30	8250219
6351293.73	615921.68	50	30	8250219

Figur 4. Et eksempel på indhold af hastighedskortet.

Indsamling af data

Baseret på erfaringerne fra det tidligere INFATI-projekt var vi klare over de problemer, indsamling af vejmidter med skiltet hastighed kunne give. Umiddelbart skulle man tro, at man blot kontakter de relevante vejmyndigheder og beder om et vejmidtetema med skiltede hastigheder og vejkode. Det er dog ikke muligt i dag.

Det har vist sig, at kun få af kommunerne har styr på hastighedsgrænserne. For amts- og statsveje, der har langt de færreste hastighedsgrænser, kan man få nogen hjælp i Vejsektorens Informationssystem (VIS), men vejmidtetemaet findes heller ikke her i en acceptabel kvalitet. I forbindelse med udviklingen af hastighedskortet havde Spar på Farten et tæt samarbejde med det tidligere Nordjyllands Amt og har derigennem fået adgang til KMS´s vejmidtetema. Det har imidlertid også vist sig at være noget mangelfuldt. F.eks. tager det på grund af KMS´s opdateringsprocedurer sommetider næsten to år fra en nye vej åbner, til den findes i vejmidtetemaet [2].

På baggrund af ovenstående forhold var status:

- Vi har fået et vejmidtetema, men dele af det kan være flere år gammelt
- Hastighederne måtte vi selv indsamle

Strategi for lagring af data

Der er principielt to måder til at få oprettet et vejmidtetema med hastigheder:

1. Hastighederne gemmes som attributter i den nyeste version af KMS' vejmidtetema
2. Der oprettes en skiltedatabase for hele Nordjylland, og der udvikles et stykke software, der automatisk kan opdatere et vejmidtetema med hastigheder

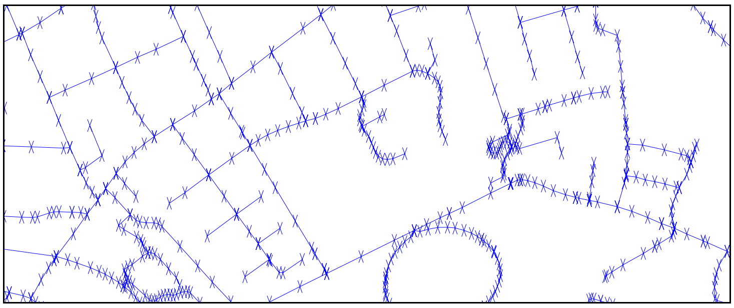
Metode 1 ser umiddelbart tillokkende ud. Men så er vi tilbage til samme strategi som Navteq og TeleAtlas benytter. Det vil sige, at projektet *Spar på Farten* selv skal vedligeholde vejmidtetemaet, f.eks. ved at finde ændringerne mellem det nye og gamle vejmidtetema leveret af KMS, opdatere vejmidtetemaet med de fundne ændringer og derefter påsætte attributter på de nye/ændrede veje. Ikke at det vil være en umulig opgave, men vi vurderede på det tidspunkt, at metode 2 vil gøre opdateringerne enklere.

Metoden beskrevet under punkt 2 tillader, at projektet får nye vejmidtetemaer fra KMS, hver gang de kommer med en 'ny' version af vejmidtetemaet (ca. 3 gange om året). Derefter kan hastighederne så automatisk generes, og ændringer til kortet er parat til at sende til bilerne næsten uden manuel indgriben.

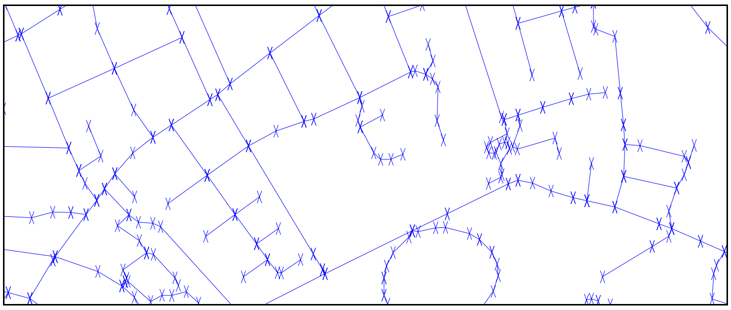
Ved at vælge metode 2 fik vi altså to databaser (vejmidter og skilte) og et stykke software, der automatisk kan opdatere vejmidterne med hastigheder.

Vejmidtedatabase

KMS' vejmidter for hele Danmark består af ca. 8.000.000 punkter. I Nordjylland er der knap 1.000.000 punkter. Reduceres punktantallet for vejmidterne, så punkter med pilhøjde under 2 meter slettes, reduceres antallet af punkter i Nordjylland til ca. 425.000. Se figur 5 og 6.



Figur 5. Vejmidter med knækpunkter markeret. Uden reduktion i punktantal.



Figur 6. Vejmidter med knækpunkter markeret. Med reduktion i punktantal. Pilhøjde min. 2 meter.

Skiltedatabase

For at få metode 2 til at virke nogenlunde smertefrit, var det nødvendigt at opbygge en skiltedatabase med følgende indhold: *Skiltetype*, *N*, *E* og *Retning*. Retningen er retningen på den vej, skiltet skal snappes ned på.

Til indsamling af data til denne opgave blev der udviklet et specialtastatur med én knap pr. hastighedsskilt. Se figur 7. Tastaturet er bygget sammen med en GPS-enhed. GPS-enheden registrerer en koordinat hvert sekund, som blev lagret på et multimediekort. Blev tastaturet rørt, blev en tastaturregistrering udløst bestående af: *ID for tast* (skiltetype) og *antal millisekunder* siden sidste GPS-registrering. Denne registrering blev lagret 'mellem' to GPS-registreringer.

Figur 7. Specialudviklet skiltetastatur.

To biler blev hver udrustet med tastatur og to studerende. Tilsammen skulle de gennemkøre de nordjyske veje, ca. 22.000 km i alt, Det tog fire uger og i alt 5.600 skilte blev registreret. Før det hele blev sat i gang, blev der mailet/ringet til alle 27 kommuner i Nordjylland for at høre, om de skulle ligge inde med materiale om hastighedsskilte/ hastighedsbegrænsninger i kommunen. Det lykkedes at få materiale fra en del af kommunerne. I alt blev der registreret ca. 90 Mb (koordinater hvert sekund + 'skiltene'). Ud fra disse registreringer er skiltedatabasen opbygget med *Skiltetype*, *N*, *E* og *Retning.* Et eksempel på en skiltedatabase fremgår af figur 8.

Skiltetype	N-koordinat	E-koordinat	Skilteretning
Lokal 60	6363122.95	587587.63	71
Byzone	6317451.38	549476.70	119

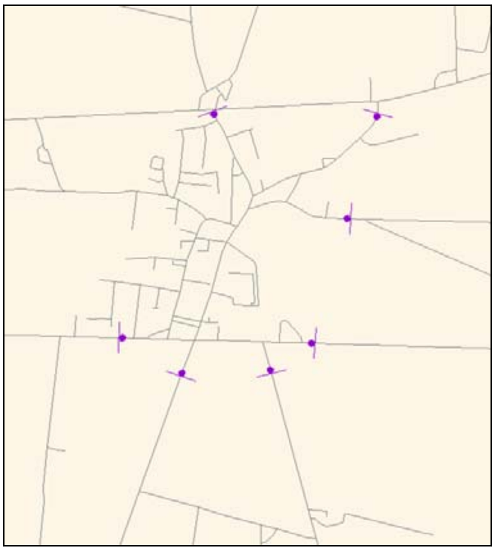
Figur 8. Eksempel på skiltedatabase.

Software til generering af hastighedskortet

Først snappes skiltepunkterne ind på vejene. Det snappede punkt bygges ind i vejmidten, og vejmidten deles i to objekter, et på hver side af det nye punkt, så der opstår en form for knudepunkt i skiltepunktet. Da der nemt kan ligge flere veje inden for en rimelig afstand fra skiltet, vægtes vejene i forhold til afstanden mellem skilt og vej og i forhold til retningsdifferencen mellem skilt og vej. Retningen får størst vægt, idet et skilt ofte står tættere på en tværvej end på den vej, som skiltet 'tilhører'. En stor vægt for retningsdifferensen bevirker et korrekt snap.
Nu skulle man tro, at der nu kun manglede:

- at pålægge 80 på hele vejnettet
- at finde *zonerne* og pålægge vejene inden for zonen med den skiltede hastighed og
- at pålægge vejene de *lokale* hastigheder (60 km/t, 70 km/t mm)

Det har imidlertid vist sig, at zonerne kun i ganske få tilfælde er lukkede. Se figur 9 for et eksempel. Pålagde man f.eks. 50 km/t i byzone, fandt programmet en vej ud af zonen, hvor der manglede et byzoneskilt. Og så havde hele Nordjylland 50 km/t på alle veje. Kun ca. 20 bysamfund ud af de ca. 350 var lukkede. Altså manglede der minimum 330 byzoneskilte!



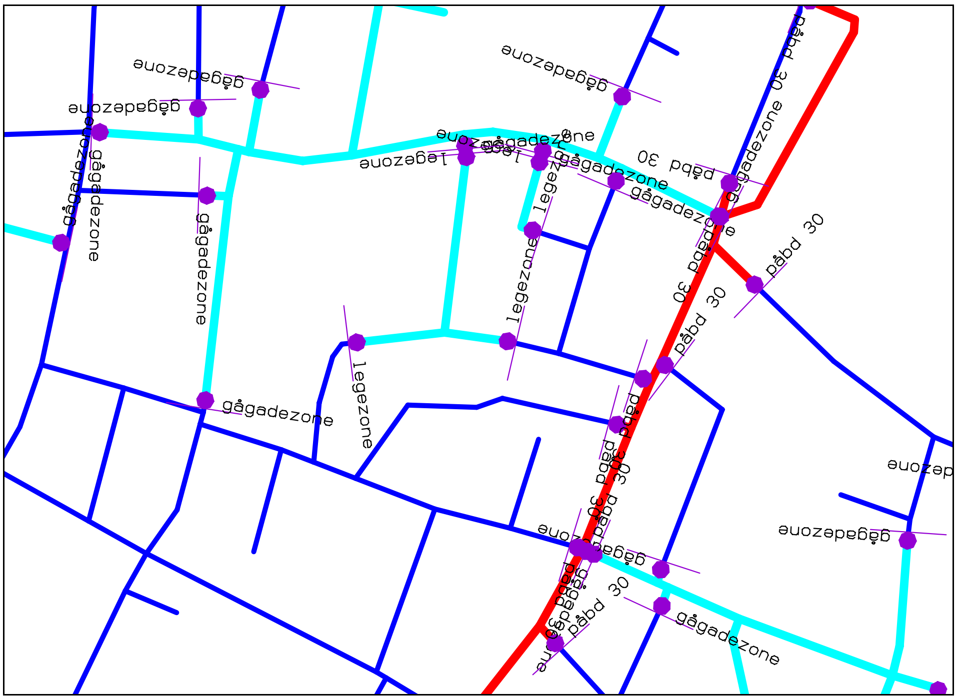
Figur 9. Byzone, der ikke lukker.

Forklaringen herpå er sparsommelighed. Byzoneskiltet på en lille grusvej med en trafikbelastning på et par biler om dagen er ofte sparet væk. Heller ikke motorvejene er én zone. Der eksisterer ikke 'motorvej ophør' på afkørselsramperne.

Vi havde også en ide om, at der skulle påføres en lokal hastighed indtil 'lokal hastighed ophør', eller indtil vejen endte blindt. Men rigtig mange steder kommer der ikke et 'lokal ophør' skilt. Det vil sige, den lokale hastighed fortsætter, indtil vejen ender blindt. Dette er ganske fremherskende i sommerhusområder. En vilkårlig grundejerforening med respekt for sig selv investerer f.eks. i et 20 km/t skilt, og placerer det på den mest trafikerede indfaldsvej til området. Da disse hastighedsskilte ofte kun er opsat i den ene retning, bliver de sjældent ophævet.

I et knudepunkt kan der i nogle tilfælde være tvivl om, ad hvilken vej påsætningen af hastighed skal fortsætte. F.eks. kan der i en Y-forgrening være tvivl, om hastigheden skal fortsætte til højre eller til venstre, fordi kortet ikke indeholder information om vigepligt i kryds. Den lokale hastighed påsættes, således at retningsændringen i knudepunktet er mindst mulig. Er dette ikke tilfældet, altså at den lokale hastighed fortsætter ad den vej, der har den mindste retningsændring, er der manuelt indsat et fiktivt skilt, der fortæller programmet, at den lokale hastighed ikke skal fortsætte ad 'denne' vej. 'Prøv den næstmindste retningsændring'. Der er således bygget rigtig mange skilte ind manuelt, for at lukke zoner (herunder motorveje), for at ophæve lokale hastighedsgrænser og for at tvinge lokale hastighedsgrænser den 'rette' vej. Derudover er der bygget en hel del 'ensretningsskilte' ind i skiltedatabasen. Disse skilte er bygget ind i rundkørsler, på vejstrækninger med midterrabat, og ved ensrettede veje.

I alt er der i dag ca. 8.600 punkter i skiltedatabasen. Den manuelle opdatering af skiltedatabasen med fiktive skilte, har været et større arbejde end forventet. Bl.a. er der udviklet software, der kan hjælpe med at finde de zoneområder, der ikke vil lukke, og de lokale hastigheder, der aldrig 'ophører'. Teknisk set er skiltedatabasen i dag korrekt. Alle zoner lukker. Ingen lokale hastigheder 'er for lange'. Dog kan det forekomme, at hastighederne på vejene ikke er korrekte, specielt i sommerhusområder, hvor de registrerede skilte er 'opdateret' med mange fiktive skilte, og beskriver de hastigheder, man forventer intensionen med den sparsomme skiltning har været. Se figur 10 for et eksempel på hvordan hastighedszoner afgrænses.



Figur 10. Screen dump fra den udviklede software til generering af hastighedskortet.

Opdatering i bilerne

Hele kortværket i bilerne er opdelt i små filer på 3·3 kilometer plus ca. 150 meter overlap mellem filerne. Ved ændringer i vejmidter og hastigheder sendes kun de kvadrater, der er berørt af ændringerne, til alle biler. Dermed formindskes omkostningerne ved opdateringerne.

Opdateringen af kortene i bilerne foregår ca. to gange om året. Der anvendes den til en hver tid nyeste version af vejmidterne fra KMS. Derudover foretages der opdateringer ved ændringer af hastigheder (nye/ændrede/slettede skilte) på de mere betydende veje. Fra den webbaserede skiltedatabase foretages et udtræk af de ændringer af hastighedsskiltene, der er sket siden sidste opdatering. Efter opdatering af skiltedatabasen påsættes hastighederne automatisk på den sidste nye version af KMS' vejmidtetema. Det nye vejmidtetema med hastigheder samt skilte sendes ligeledes til et webkort, der bruges til opdatering og det kort, der viser deltagernes strafpoint.

Vedligeholdelse af hastighedskortet

Erfaringer fra andre digitale kort

I forbindelse med opbygning og ikke mindst vedligeholdelse af digitale kort har der flere steder i såvel Danmark som i udlandet kunnet konstateres problemer. Herunder følger en kort gennemgang af nogle af de erfaringer, der er gjort.

I Norge blev en fælles digital vejdatabase gældende for kommunerne og staten oprettet i 1999. Fire år senere havde en stor del af kommunerne endnu ikke bidraget til databasen [3]. Også engelske og hollandske statslige notater beskriver vedligeholdelsen af et hastighedskort som en af de største udfordringer ifm. et eventuelt ISA-projekt [4],[5]. Tillige blev et nyligt afsluttet svensk ISA-projekt forsinket ét år, primært pga. problemer med hastighedskortet [6].

De private udbydere, som er blevet kontaktet ifm. denne undersøgelse, har også konstateret at opdateringer fra myndighederne alene ikke er tilstrækkeligt til en tilfredsstillende kortkvalitet. Krak baserer deres kort på DAV (Dansk adresse- og vejdatabase), hvorfra de modtager en årlig opdatering. Desuden kontaktes vejmyndigheder på alle niveauer ad hoc. Der er ingen standardprocedurer for disse kontakter, men de foretages, når der opnås kendskab til nye projekter osv. Endelig modtager Krak en stor mængde feedback fra bruger af deres kort, som efterfølgende verificeres af vejmyndighederne [7]. De Gule Sider baserer deres kort på opdateringer fra Kort & Matrikelstyrelsen og feedback fra deres brugere [8].

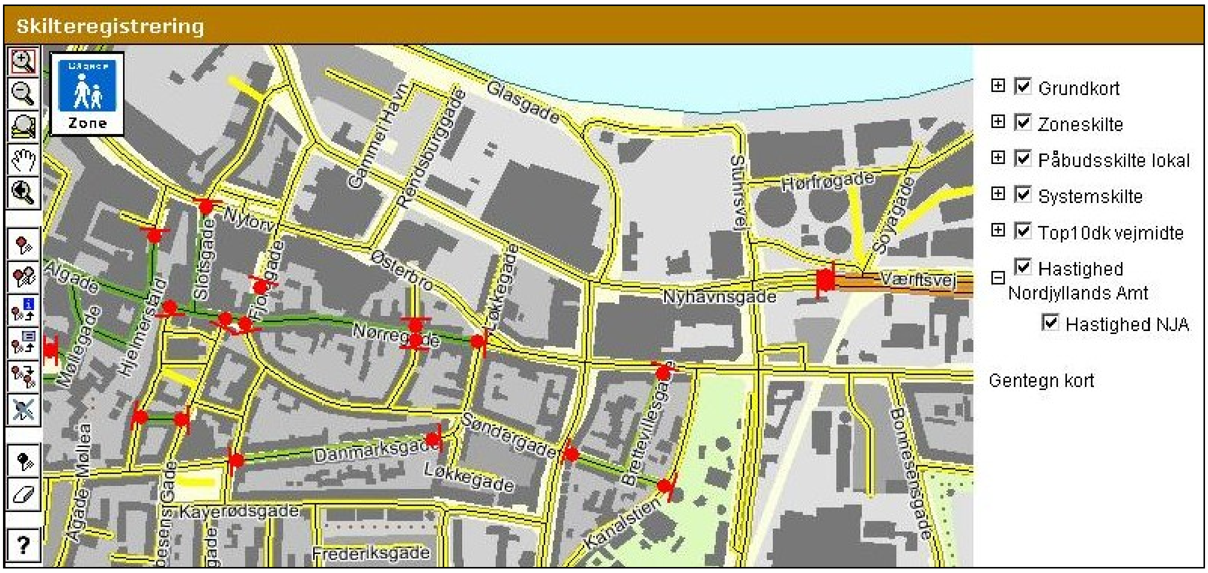
En af de store internationale kortudbydere, Teleatlas, baserer sit digitale kort på et udtræk fra DAV fra starten af 1990erne. Med dette som udgangspunkt bruges en del markmedarbejdere samt brugernes feedback til opdateringer. Dette suppleres med oplysninger fra kommunerne og Vejdirektoratet. Endvidere er mobile mapping ved at blive en vigtig del af opdateringsproceduren. Hovedvejene gennemkøres og registreres én gang årligt og de mindre veje hvert fjerde år. Der anvendes ikke nye opdateringer fra DAV. [9]

Vedligeholdelse af Spar på Farten kortet

Grundlæggende er der to tilgange, når et digitalt hastighedskort skal vedligeholdes. 1; Med udgangspunkt i et givent hastighedstema foretages løbende opdateringer i den takt der opnås kendskab til ændringerne. Det er en administrativ nem metode, men ulempen er, at kortet "vokser" fra de officielle kort, som vejmyndighederne bruger. 2; Et hastighedskort lavet og vedligeholdt med feedback fra de berørte vejmyndigheder. Denne metode er sværere at administrere, men i teorien skulle hastighedskortet altid være opdateret, da vejmyndighederne selv skulle være interesserede i det. I forventning om at få det mest præcise hastighedskort, er tilgang 2 valgt til *Spar på Farten*.

Vedligeholdelsen af hastighedskortet i *Spar på Farten* består af to kilder. Den ene er feedback fra deltagerne. Det foregår normalt via e-mail og efterfølgende verificeres det ved at kontakte den relevante vejmyndighed og/eller besøge lokaliteten. Den anden er løbende opdatering fra vejmyndighederne, så man sammen med dem altid har et opdateret hastighedskort. Den førstnævnte er nem at administrere, men må forventes at have bias, da deltagerne kun sjældent indberetter om for høje hastighedsgrænser. Den anden skulle i teorien give et kort, der altid er opdateret og korrekt, men som det beskrives herunder, har erfaringerne været noget blandede på dette område.

En webapplikation der gør det nemt at opdatere ændrede hastighedsskilte og -grænser blev udviklet som en del af *Spar på Farten*. Her kan kommunerne gå ind og oprette/ændre/slette hastighedsskilte og dermed dels hjælpe Spar på Farten og dels altid have et fuldt opdateret hastighedskort til rådighed. Et screen dump af webapplikationen fremgår af figur 11.



Figur 11. Screen dump af webapplikationen, hvor der er muligt at ændre hastighedsskiltene.

Stort set alle 27 kommuner i det gamle Nordjyllands Amt lovede at opdatere hastighedskortet løbende, når der skete ændringer på deres vejnet. En god del af kommunerne har da også bidraget med opdateringer, mens andre har været mindre entusiastiske. Siden Spar på Farten startede, er kommunerne blevet kontaktet flere gange for at få dem til at forpligte sig til at bidrage til vedligeholdelsen af hastighedskortet.

Kommunernes kendskab til Spar på Farten

I efteråret 2004 blev alle kommunerne besøgt af et medlem af projektet og blev introduceret til førnævnte webapplikation. Besøget blev gentaget primo 2005, hvor kommunerne igen blev opfordret til at indsende opdateringer. Erfaringerne var, at en mindre del af kommunerne ikke kunne afsætte ressourcer til opdateringen, samt at nogle var usikre på IT og derfor ikke ville anvende webapplikationen. På baggrund af dette besøg opnåedes følgende erfaringer:

- Ca. 15 % af kommunerne havde fravalgt opdateringerne pga. manglende ressourcer.
- Ca. halvdelen var meget interesserede og hjælpsomme omkring hastighedskortet.
- Ca ⅓ havde aldrig prøvet webapplikationen.
- Ca. ⅓ havde prøvet webapplikationen men aldrig brugt den.
- Den sidste ⅓ brugte webapplikationen når der var opdateringer.
- Der var en tendens til, at de større kommuner var lidt bedre til at bruge webapplikationen.

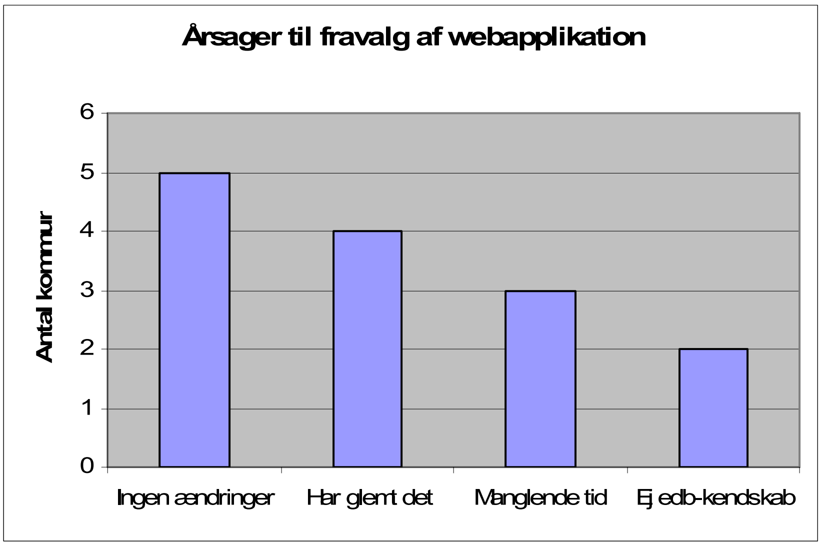
I september 2006 blev 26 positivt indstillede kommuner kontaktet via telefon for at høre om deres brug af webapplikationen. Her blev der spurgt ind til: Brug af webapplikationen, brugervenlighed, eventuelle opdateringsprocedurer, årsager til fravalg af applikationen, samt hvordan hastighedsgrænserne bliver registreret i de enkelte kommuner. Dette blev suppleret med et spørgsmål omkring deres vurdering af indsatsen når kommunalreformen er faldet på plads.

I to kommuner arbejdede kontaktpersonen ikke længere ved kommunen, mens arbejdsområdet i to andre kommuner var overdraget til en kollega. Kendskab til projektet og webapplikationen var dog ikke overdraget. Størsteparten af de kontaktede kommuner var meget positive, mens en enkel kontaktperson var utilfreds med projektet og opdateringsproceduren.

Brug af Webapplikationen

Siden sidste besøg primo 2005 havde 54 % ikke brugt webapplikationen. 46 % havde besøgt applikationen, men kun 38 % havde foretaget opdateringer.

Det betyder, at der ikke er kommet opdateringer fra kommuner, der administrerede 4.000 km ud af 7.800 km kommunevej i Nordjyllands Amt. Årsagerne hertil fremgår af figur 12.



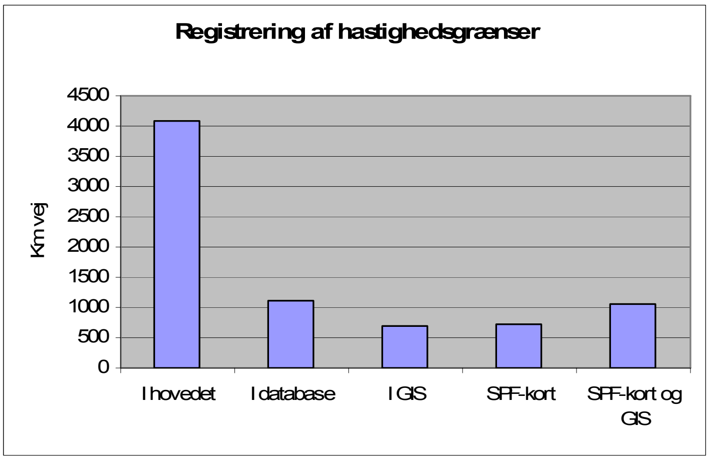
Figur 12. Årsager til manglende brug af webapplikationen.

28 % af kommunerne sagde, at de havde glemt webapplikationen. 21 % sagde at de ikke havde tid til opdateringerne, mens kun 14 % sagde, at manglende IT-kendskab var årsagen. De sidste 37 % sagde, at der ikke havde været ændringer i hastighedsgrænserne i perioden. Omkring sidstnævnte gruppe må det siges, at perioden var temmelig lang, ca. 1½ år, men at der internt i projektgruppen er registreret flere ændringer i disse kommuner, som den kontaktede medarbejder åbenbart ikke havde kendskab til eller havde glemt.

Problemet med manglende IT kendskab er blevet reduceret siden 2005, hvilket må betragtes som i tråd med den generelle udvikling i samfundet. Hvorvidt manglende tid eller uændrede hastigheder kan forklare, at webapplikationen var blevet gemt, er uklart, men den nyligt overståede kommunalreform har formodentligt trukket i negativ retning.

Hvordan registrerer kommunerne deres hastighedsgrænser

Før kommunalreformen var de nordjyske kommuner ansvarlige for ca. 7.800 km kommuneveje, hvilket svarer til ca. 85 % af de offentligt administrerede veje i amtet. Figur 13 viser hvordan hastighedsgrænserne administreres.



Figur 13. Administration af hastighedsgrænserne på det kommunale vejnet.

I de fleste små kommuner findes intet centralt register, og de ansvarlige personer har hastighedsgrænserne i hovedet[1]. Hvis der er tvivl om en hastighedsgrænse besøges lokaliteten. Enkelte af kommunerne supplerer dette med brug af Spar på Farten webapplikationen som opslagsværk - hvilket jo var en af hovedideerne med kortet. I de fleste større kommuner er der i en central database med hastighedsgrænserne. For enkelte af disse er det kun dele af deres vejnet, der i en database, f.eks. hovedbyens veje. Andre styrer hastighedsgrænserne i et GIS-tema. Endelig supplerer en enkel af kommunerne deres GIS-tema med opslag i Spar på Farten kortet.

Dermed findes der intet register over hastighedsgrænsen for 53 % af kommunevejene og kun 23 % eller ca. 1.800 km har registreringerne i et GIS-tema og dermed tilgængeligt på et kort. Baseret på disse erfaringer, må det siges, at der er lang vej før et opdateret digitalt hastighedskort findes for alle kommunerne i det nordjyske.

Fremtidige procedurer

Det fremgår ovenfor, at vedligeholdelsen af hastighedskortet ikke har fungeret så godt som forventet. Mange kommuner har ikke haft ressourcer til opdateringen, der derfor må betragtes som mangelfuld. Der er dog næppe tvivl om, at den nyligt overståede kommunalreform har forværret

[1] De fleste hastighedsgrænser er selvfølgeligt blevet godkendt af det lokale politi på et tidspunkt og må derfor være beskrevet i et notat. Det er imidlertid ikke noget der anvendes efterfølgende, og det fungerer derfor ikke som et register, der kan slås op i.

ressourcesituationen. Et andet forhold er kommunestørrelsen. I små kommuner er det tekniske personale få og har derfor en meget bred vifte af opgaver hvor imellem en lille opgave som vedligeholdelse af hastighedskortet måske forsvinder. Med de nye større kommuner med mere specialiserede medarbejdere forudså en del af de adspurgte kommuner, at et bedre vedligeholdelsesniveau for det digitale hastighedskort kunne forventes.

Konklusion og diskussion

Vores erfaringer med hastighedskortet i Spar på Farten viser, at det er relativt enkelt og økonomisk overkommeligt at oprette et digitalt hastighedskort over Nordjylland. Den virkelige udfordring er at vedligeholde kortet. Vi fik udviklet en brugervenlig webapplikation, som alle vejadministratorerne kan bruge. Vi lavede en frivillig opdateringsprocedure - vi havde ikke andre muligheder. Vi forsøgte at overbevise kommunerne om vigtigheden af opdateringerne og de fordele, som kommunerne selv kan få ud af arbejdet. Vi må konstatere, at kun en mindre del af kommunerne leverer en troværdig opdatering til hastighedskortet. Vores konklusion er derfor, at man ikke kan få et hastighedskort af tilstrækkelig høj kvalitet, hvis det skal baseres på frivillig vedligeholdelse hos kommunerne.

§ 10 i Lov om offentlige veje siger at det påhviler vejbestyrelserne at holde deres offentlige veje i den stand, som trafikkens art og størrelse kræver. Vores anbefaling er, at der laves en ændring i denne lov, så det også bliver obligatorisk at lave og vedligeholde et digitalt hastighedskort, der skal være tilgængelige for offentligheden. Det er den eneste måde, hvorpå man kan få et digitalt hastighedskort af tilstrækkelig kvalitet. Dette er i tråd med Færdselssikkerhedskommissionens Handlingsplan [10].

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Intelligent Speed Adaptation in Company Vehicles

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Abstract — **This paper describes an Intelligent Speed Adaptation project for company vehicles. The Intelligent Speed Adaptation function in the project is both information and incentive, which means that the Intelligent Speed Adaptation equipment gives a warning as well as penalty points if the driver is speeding. Each month the driver with that month's fewest points wins an award. The paper presents results concerning speed attitude on the first three of a planned 12 months test period. In all 26 vehicles and 51 drivers from six companies participate in the project. The key result is that speeding is reduced from 18.7% to 7.4% on urban roads with a speed limit of 50 km/h while it is reduced from 18.9% to 4.7% on rural roads with a speed limit of 80 km/h.**

I. Introduction

TRAFFIC is one of the factors in the industrial world that costs most fatalities to say nothing of the millions of injured persons. Even though the number of fatalities in Europe has been reduced by some 17% from 2001 to 2005 more than 40,000 fatalities happened every year on the European roads and the European Union is still a big step from the goal of less than 25,000 fatalities before 2010 [1]. There are several groups of road users, who contribute especially negatively regarding traffic safety e.g. bicycle riders, moped riders, youngsters and drivers of commercial vehicles. In many countries - also Denmark - commercial vehicles have a bad reputation among other road users due to their speed behaviour, and in addition they are notably over-represented in traffic accidents. The commercial vehicles are often bigger than the average cars, and when accidents happen the accidents are more severe [2]. These differences result in nearly 30% more fatalities and seriously injured than for passenger cars [3].

So, reducing the number of fatalities regarding commercial vehicles in traffic is an important issue in the road safety work and Intelligent Transport Systems and especially Intelligent Speed Adaptation (ISA) seems to be an efficient measure [4].

ISA means systems which compare the speed of a car with the speed limit on the location. In most new ISA projects the geospatial position of a car compares its current position and speed with a digital road map which includes the speed limit, and the equipment responds if the speed limit is exceeded. There are various forms of response if speeding: the response can be visual and/or auditory. Another possibility is to log every speed limit violation on an on-board computer. Finally, the accelerator pedal can give resistance or even make it impossible to speed. These different types of ISA systems can be categorized as informative, advisory, recording or intervening systems [5].

In the last decade a number of ISA field trials in several European countries and in Australia have shown the potential of ISA. The results differ depending on the ISA equipment, the test area and if there is a sort of incentive involved in the systems. The large-scale Swedish trials in Borlänge, Lidköping, Lund and Umeå during the period 1999-2002 have involved approximately 5,000 cars and the main result was an average speed reduction of 3 to 4 km/h [6].

In the Australian TAC Safecar project, which was carried out in the Melbourne area from 2002 to 2004, a reduction by up to 2.7 km/h was found for the 85 percentile speed. Furthermore, speeding by more than 5 km/h was reduced by up to 57% [7].

Moreover, field trials in Belgium [8], United Kingdom [4], the Netherlands [9] and Denmark [10] have shown promising results.

In addition, an ongoing Danish ISA project, "*Pay as You Speed*" has shown the possibilities with ISA. In this project the driving behaviour is directly connected to a discount on the car's insurance rate - the less speeding the less insurance rate. The first results show that speeding by more than 5 km/h is reduced from 16% to 3% on urban roads and from 28% to 2% on rural roads. [11], [12], [13].

A few ISA projects are carried out with commercial vehicles.

In Stockholm, Sweden an ISA project with 20 public cars and in all 130 test persons was carried out 2003-2005. The highest impacts were found for rural roads with a speed reduction of up to 2 km/h. On motorways the impact was less and no impact was found on roads with 30 km/h speed limit [14].

A Belgian ISA trial with both private and commercial vehicles was carried out in City of Ghent. In all 17 commercial vehicles were involved in this study, most of

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them from the local authorities and public transportation. No separate results were given for the commercial ones. However, a reduction of up to 2.5 km/h was found for the 85% percentile speed for all cars [8].

In addition a Swedish trial with 16 buses was made in Gothenburg in 2002 to 2003. Even though most of the participating drivers found it essential to observe the speed limits, they were rather negative to ISA. No driving results were published [15].

So far ISA in commercial vehicles has shown significant results regarding speed, but the drivers' attitudes are quite negative. Until now no ISA projects have tested the impact on commercial drivers from different kinds of incentive.

Therefore, in this paper the ISA impact on professional drivers from combining information about speeding with incentive in the form of a competition to get the fewest logged speed violations is presented.

II. Methods

A. Project specification

The current project which is carried out in cooperation between Vejle Municipality and Aalborg University is in general based on the same technology as in the *Pay as You Speed* project [12]. However, there are some differences and a brief description of the equipment follows here.

In the vehicle there is an "On Board Unit" (OBU) which consists of:

- GPS/GPRS unit with a memory card where the digital map with the speed limits are stored. It is placed under the dashboard.
- Display and loudspeaker placed in the air nozzle, the display shows the speed limit and penalty points – See below.
- GPS antenna, placed behind the rear-view mirror
- A "key reader" which can read the drivers key ID.

Fig. 1 shows a flow chart for the ISA.

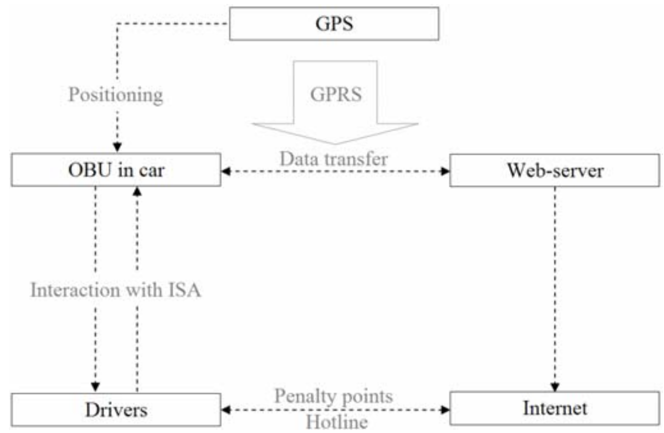

Fig. 1. The flow in the ISA.

The GPS receiver in the OBU calculates a position every second. This position is matched onto the speed map; the speed limit from the map is shown in the display and compared with the car's speed. If the speed limit is exceeded by more than 5 km/h, the OBU gives the driver a verbal warning with a female voice as e.g.; *"50 – you are driving too fast*". The warning will be repeated every sixth second until the speed is below the speed limit + 5 km/h. The third and subsequent warnings give penalty points. The number of penalty points per warning depends progressively on the degree of speeding so a small violation does not give as many penalty points as a large one. The participating drivers have access to a web based map which shows all penalty points immediately after the trip has ended. Here it is possible to check if the OBU has calculated the right speed limit and position. A hotline can be contacted for removing incorrect penalty points. Fig. 2 shows the map with penalty points.

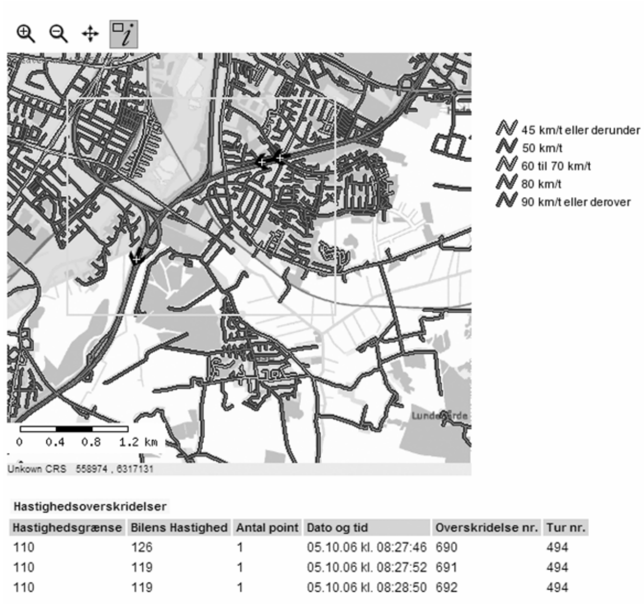

Fig. 2. The map with penalty points.

The penalty points are shown on the display and summarized for each driver, and once a month the driver with fewest points wins an award sponsored by the local municipality. Each participating company has the opportunity to supply this award or give an award to the "best" driver in the company, if so desired. The drivers have access to a webpage which shows the number of penalty points per driver, but only names from the driver's own company are shown while the other drivers are anonymous. The webpage also shows the results for each firm in total.

Each driver has a personal key ID which must be shortly in contact with the display when initiating a trip. Fig. 3 shows the ISA equipment.

Fig. 3. The ISA equipment consisting of the display in the air nozzle (above) and the On Board Unit (below).

This ISA project involves 26 commercial cars and a total of 51 drivers in one year. The cars were equipped with the hardware in the spring of 2007. The cars are planned to drive with the equipment for one year. In the first 1½ months after installation the display was turned off and no warnings were given. However, the OBU also in this period logs all speeding. In this way the period is a baseline period where the normal behaviour in each vehicle is registered. After the baseline period the displays are turned on in the rest of the test period.

In this article the impact from ISA in the first 1½ months "baseline period" with the ISA equipment turned off will be compared with the first 1½ months with active ISA equipment, subsequently named the "effect period".

Six companies are participating in this project. Four of them are small/medium companies; one is the local post office and the last is the road office in the local municipality. In the four small/medium companies each participating car has been driven most of the time by the same driver. This means that the driving registered for the single car is almost similar to what is registered for the single driver. In the large company in all 28 drivers are using five cars. In the road office seven drivers use five cars. Table I shows the distribution of drivers and vehicles in the participating companies.

TABLE I
PARTICIPATING CARS AND DRIVERS IN THE SIX COMPANIES.

	No. of participating vehicles	No. of participating drivers
Small medium enterprise	5	5
Small medium enterprise	5	5
Small medium enterprise	5	5
Small medium enterprise	1	1
Municipality	5	7
Large company	5	28
Total	26	51

After activating the ISA equipment, the number of penalty points and the mileage is calculated every month and compared for each driver. The driver with the lowest number of penalty points per driven 1,000 km receives a reward.

During the same procedure any systematic avoidance of using the key ID is monitored and a warning is sent to the manager in the company.

Besides this study on behaviour a study on the participating drivers' attitudes to ISA and traffic behaviour in general will be carried out. Here data will be collected via a web based questionnaire which all participating drivers have been asked to fill in. One questionnaire was sent out during the "baseline period" while the next will be sent out late in the project period. With these questionnaires it will be tested if participating in the ISA project will change the drivers' attitudes to ISA and the attitude to traffic related questions in general and especially speeding.

III. DATA AND RESEARCH PROCEDURES

A. Experimental set-up

In the "baseline period" and the first 1½ months with the ISA equipment turned on, the "effect period", the 26 participating cars have driven approximately 88,000 km in total, of which the majority is distributed on the following road types:

- Roads with a 50 km/h speed limit, which is the normal speed limit in urban areas (subsequently named as 50 km roads etc.),
- Roads with a 70 km/h speed limit, which is the speed limit on a few large city roads,
- Roads with an 80 km/h speed limit, which is the normal speed limit in rural areas,
- Roads with a 110 km/h speed limit, which is the lowest normal speed limit on motorways and the speed limit on motorways in the study area and
- Roads with a 130 km/h speed limit, which is the speed limit on motorways in less trafficked areas.

In all, 94% of the 88,000 km are driven on these roads, and hence the results are based on mileage on roads with these speed limits. The mileage distributed on all speed limits is shown in table II.

TABLE II
MILEAGE DISTRIBUTED ON SPEED LIMITS.

	Mileage (km)	
Speed limit (km/h)	Baseline period	Effect period
30	206	199
40	554	602
50	12,092	10,700
60	781	575
70	3,377	2,951
80	22,886	19,648
90	1,318	1,318
110	2,684	3,836
130	1,958	2,053
Total	45,855	41,881

The participants' behaviour is registered by 9.9 million GPS positions in all. This number of data corresponds to approximately 1.6 hours of driving per participating vehicle each weekday.

B. Research procedure

When studying speeding, the use of time can result in a systematic bias, since a large violation of a speed limit on a given distance will be underestimated because the higher the speed is, the less time will be spent on this distance. Hence, a small violation close to the speed limit will result in a longer time of speeding than does a large violation on the same distance. Therefore, all results are based on mileage and not on the time span.

The ISA equipment in this project starts to give warnings every 6th second if the speed limit is exceeded by more than 5 km/h, and after two warnings also penalty points. The speed limit plus 5 km/h is selected because most Danish road users are driving close to the speed limit, but not necessarily below it. If the system was designed to react already on the speed limit, it was assessed that the participants would often feel pressure from the cars behind them. Also the Danish rules concerning speeding are included in this assessment: Fines are only received if speeding is exceeding the limit by more than 10% + 3 km/h. Therefore the part of speeding above the speed limit + 5km/h will be compared in this study.

The behaviour of the cars is studied in the "baseline period" and in the "effect period" by comparing the proportion of the mileage that has been driven at more than 5 km/h faster than the speed limit in the two periods.

To handle that there are more than one driver per vehicle, the drivers must use a key ID. The frequency of the drivers' use of the key ID is studied to see if they forget to use the key ID, maybe especially when they are busy. To test this, the part of speeding using the key ID will be compared with the part of speeding not using it.

Since speeds far below the limit can not be influenced by ISA, these speeds are sorted out of the data when calculating "mean free flow speed" (MFFS) and speed variation. There is no indisputable definition of "free flow speed". A number of scientists working with ISA related subjects have been contacted via "the International Working Group On Speed Control" (IWGOSC) mailing list and a large number of suggestions have been made. One suggests all speeds above 15 km/h while others suggest that free flow is all data when speed is above 50 km/h on motorways. In the Australian TAC SafeCar Project the vehicles had a following distance warning (FDW) system and hence they could deselect data if the car in front was closer than three seconds [7]. A fourth suggestion was to remove all mileage during the rush hours. However, the vehicles in this ISA project are not equipped with FDW and if all mileage in the rush hours is removed, the number of data will be low and hence assessed as too uncertain. Consequently, we have decided the following limits of speed when defining "free flow speed". On 50, 70 and 80 km roads, it is minus 15 km; on 110 km roads it is minus 20 km/h and on 130 km roads it is minus 30 km/h. The definition of "free flow speed" here is a trade-off between two considerations; 1: As much data as possible and hence the results may be the most reliable and 2: Avoid data far below the speed limit and thus of no relevance when measuring ISA. See table III.

The standard deviation indicates the range of speed on a road. If it is small it means that most of the traffic is driving at an almost similar speed. Investigations have shown that a decrease in the standard deviation will improve the traffic safety [16]. The standard deviation (FFSD) is here calculated on "free flow speed".

TABLE III

SPEEDS FOR EACH SPEED LIMIT, WHICH IS INCLUDED IN "FREE FLOW SPEED".

Speed limit	50 km/h	70 km/h	80 km/h	110 km/h	130 km/h
Free flow speed	>35 km/h	>55 km/h	>65 km/h	>90 km/h	>100 km/h

Finally, the impact from ISA on transportation time will be studied. It is essential that any increase in transportation time is calculated because most companies are very aware of the expenses regarding transportation including downtime, and they might reject to participate in an ISA project if it results in too large or unknown increases in transportation time. The change in transportation time is calculated on "free flow speed" for the same reasons as mentioned concerning MFFS.

C. *Statistical analyses*

In Section IV a paired t-test is used to study differences between e.g. the "baseline period" and the "effect period" for various variables. Regarding e.g. proportion of mileage with speeding we compute for each car the difference between this variable in the "effect period" and the "baseline period". This leaves up to 26 observed differences and we then apply a standard t-test to test whether the theoretical mean of these differences is significantly different from zero. Note for some speed limit classes, some cars did not attain any mileage. Hence, for some speed limit classes the number of observed differences is lower than 26.

The MFFS shows the impact of ISA on speeds close to or above the speed limit. For each car we compute a MFFS by weighting each MFFS value with the proportion of the mileage travelled at this speed. Similarly we compute a mean squared deviation (variance) by weighting the squared distances between the free flow speed values and the MFFS with the proportions of mileages for the speed values. The standard deviation FFSD for each car is the square root of these mean squared deviations. The quantity FFSD is of interest as it measures the homogeneity of the driving pattern.

The MFFS and FFSD for one of the cars with just one driver differ markedly from the values for the other cars. In the effect period for e.g. on 50 km roads, this driver's MFFS is 11.7 standard deviations above the mean of the remaining cars' MFFS. In the baseline period this driver's behaviour does not differ from the other cars. This pattern is repeated for FFSD and is consistent for all speed limits. It thus appears that the driver is intentionally obstructing the ISA experiment by deliberately driving faster in the effect period. In the analyses below we omit this driver and briefly comment on the results obtained if the driver is included.

IV. Results

A. Part of speeding

Table IV shows the % of the mileage with a speed exceeding the speed limit by more than 5 km/h.

TABLE IV.
PERCENTAGE OF MILEAGE OVER THE SPEED LIMIT + 5 KM/H.

	Speed limit (km/h)				
	50	70	80	110	130
Baseline period	18.7	15.2	18.9	25.5	5.0
Effect period	7.4	5.1	4.7	6.6	1.3
Reduction	11.3	10.1	14.2	18.9	3.7
p-value	0.000	0.000	0.000	0.016	0.290

There has been an impact on the participants' speed on all roads. The largest impact has been on 80 rural roads and 110 motorways and the smallest on 50 and 70 urban roads and 130 motorways. The speeding percentage has in general been at the same level on urban and rural roads in the baseline period. This is different compared to results from two other Danish ISA projects. In these projects the violations in the baseline period were much higher in rural areas than in urban areas. Opposed to this, the impact from ISA in these projects was highest on rural 80 km roads which fits better with the present results [10] [11], [13]. On 130 km roads, the impact is infinitesimal and the amount of speeding is probably low since a majority of the drivers find that 130 km/h is fast enough and hence speeding is unnecessary. This indicates that drivers in company cars in general have a worse attitude than the private car owners to speeding in urban areas and hence more accidents which also is found in the literature [2], [3]. On urban 50 km roads, the speeding is more than halved from 18.7% to 7.4% but the relative impact is higher on 70 km roads: from 15.2% to 5.1%. On rural 80 km roads, the impact is a reduction from 18.9% to 4.3% and on 110 km motorways from 25.5% to 6.6%. On 130 km motorways, the speeding is reduced from 5.0 % to 1.3 %. All reductions expect for 130 km roads are statistically significant at the 5% significance level according to the paired t-tests, cf. III C.

B. Use of key ID

In the effect period the participating drivers were asked to use a personal key ID. However, some of them refused to use the key ID while other used it from time to time. The mileage with or without used key ID in the effect period can be seen in table V.

TABLE V
MILEAGE WITH/WITHOUT USING KEY ID.

	Baseline period	Effect period	
Speed limit (km/h)		Without key ID	With key ID
30	206 km	33 km	165 km
40	554 km	143 km	459 km
50	11,805 km	2,977 km	7,610 km
60	735 km	121 km	433 km
70	3,150 km	783 km	2,067 km
80	21,290 km	4,204 km	15,002 km
90	1,260 km	272 km	1,030 km
110	2,638 km	207 km	3,607 km
130	1,915 km	69 km	1,978 km
Total	43,554 km	8,808 km	32,351 km

In total 79% of the mileage has been carried out while using a key ID. Especially when driving on 110 and 130 km roads the proportion of key ID use has been high with 95% and 96%, respectively. This proportion should have been near to 100% and therefore the monthly study of each driver's use of key ID has been reported to the reluctant drivers' leaders. Even though there is a monitoring of the key ID use some of the drivers are averse to using it.

A big difference in the drivers' use of key ID is found. In some cars the key ID is always used and in other cars the drivers often forget to use the key ID. Table VI shows the number of cars in different percentage intervals for mileages driven with key ID.

TABLE VI
NUMBER OF COMPANY CARS DISTRIBUTED ON THE PROPORTION OF MILEAGE WHEN USING KEY ID

Proportion mileage with key ID	0-25%	26-50%	51-75%	76-100%
Number of cars	7	1	0	18

The drivers in most cars use the key IDs in the majority of the mileage. The impact from using key ID can be seen on table VII.

TABLE VII
PERCENTAGE OF MILEAGE OVER THE SPEED LIMIT + 5 KM/H DEPENDING ON USE OF KEY ID.

	Speed limit (km/h)				
	50	70	80	110	130
Baseline (No key available)	18.7	15.2	18.9	25.5	5.0

Effect, without Key	13.6	9.7	11.0	3.0	0.3
Effect, with Key	4.2	2.9	2.5	6.9	1.4
p-value	0.014	0.009	0.056	0.403	0.500

When not using the Key ID the drivers were speeding more than when using it, but still the speeding was less than in the "baseline period". So based on these first results, it is found that even without incentive (penalty points on the drivers key ID) the information part of the system has an impact on speed behaviour, in accordance with findings in other ISA projects [7], [8].

Except on 130 km roads, the use of key ID seems to reduce speeding more than informative ISA alone. However, only on 50 and 70 km roads the extra reductions based on use of key ID are significant at the 5% significance level. The insignificant results for 110 and 130 km roads may be explained by lack of data, only 3 and 2 difference observations were available for these speed limits.

C. *Mean free flow speed*

The MFFS shows the impact from ISA on speeds close to or above the speed limit. In table VIII the MFFS and the FFSD are compared for the different speed limits.

TABLE VIII
MFFS AND FFSD IN THE BASELINE AND EFFECT PERIODS.

Speed limit (km/h)		Baseline	Effect	Reduction	p-value
50	MFFS	50.5	47.9	2.6	0.000
	FFSD	10.0	9.5	0.5	0.000
70	MFFS	69.6	66.4	3.2	0.000
	FFSD	9.4	8.3	1.2	0.000
80	MFFS	82.2	76.8	5.4	0.000
	FFSD	11.4	9.6	1.8	0.000
110	MFFS	113.5	107.4	6.2	0.002
	FFSD	15.2	8.3	6.9	0.023
130	MFFS	120.2	121.0	-0.8	0.941
	FFSD	10.4	9.1	1.3	0.654

Not surprisingly, the same trends as mentioned above can be found when studying MFFS. The biggest reduction 5 – 7 km/h is found on 110 motorways and on 80 roads, on urban roads the reduction is between 2 and 4 km/h. On 130 motorways, there has been an increase in speed of nearly 1 km/h. The results are very similar to the primary results in the *Pay As You Drive* project [11].

The FFSD is reduced on all road types, from 0,5 km/h on 50 km roads and up to 7 km/h on 110 km motorways. As the reduction in percentages speeding and the free flow speed a reduction in the FFSD also indicates better traffic safety.

Except on 130 km roads all the reductions in MFFS and FFSD are significant at the 5% significance level according to paired t-tests. If the differences for the obstinate driver are included in the statistical analyses the observed reductions are still positive, but not significant anymore (except at speed limit 80 km/h) since the data for this driver both inflates the variance and leads to smaller observed reductions.

D. *Transportation time*

The increase in transportation time is very low. In average each participating car has used 11:51 minutes more per week for transportation which can reasonably be related to the ISA system. According to Danish socio-economic estimations an hour of wasted time for a commercial car is priced as 35 € [17]. Hence, the weekly expenses regarding increased transportation time per vehicle is 6.9 €. As a supplementing comment to this result it must be remembered, that some 40% of the transportation among the participating cars has been carried out with speeds lower than 'free flow speed' and hence of no relevance for ISA.

V. DISCUSSION

In this study the drivers are under influence from two factors – an information influenced through the female voice *"50 – you are driving too fast*" and an incentive influence through the penalty points. If it is presumed that when driving without key ID the drivers are not under influence from the incentive "penalty points" this primary study has shown that both influences give a significant impact. It will be exciting to see the development in the remaining part of the 12 month test period. Will the total effect increase or decrease over time? Will the mileages without key ID increase or decrease and what will the effect be on the speed? Will the speed increase or decrease over time when the drivers get used to the ISA equipment? And what about the effect of the incentive – the penalty points? Will the drivers get used to the penalty points? And how will the companies handle the penalty points: will they give awards to their driver with the smallest number of penalty points or will they punish the driver with most speeding – or maybe do nothing and leave the "job" to be solved in a social process between the drivers when they are discussing their penalty points over the lunch table?

VI. CONCLUSION

The aim of this study of ISA in company cars is to test the combination of incentive and information. It is shown that ISA has a significant impact on the drivers speed. These primary data show that the percentage of mileages with speeding on 50 urban roads is reduced from 18.7% to 7.4% and on 70 roads from 15.2% to 5.1%. On roads with higher speed limits the impact is even bigger. On rural 80 km roads, a reduction from 18.9% to 4.7% is found, while it is the biggest on 110 km motorways where mileages with speeding is reduced by 19.3% from 25.5 to 6.6%. On 130 motorways, only a minor part of the mileage was with speeding in the baseline period but still the speeding has decreased in the effect period.

It has also been shown that the use of the key ID improves impact from ISA. It indicates that incentive supplies information alone and that the combination is better than informative ISA solely. The percentage of mileages with speeding on 50 km urban roads is reduced to 13.6% without using key ID while it is as low as 4.2% when using key ID. The results on 70 km roads are 9.7% and 2.9% while they are 11.0% and 2.5% on 80 km roads. On 110 and 130 km motorways some small increases are observed when using key ID. The impacts from using key ID are significant for 50 and 70 km roads while the results for the remaining roads are insignificant.

Moreover, the data shows that "mean free flow speed" and "free flow standard deviation" have been reduced significantly because of ISA. Impact has been most marked on rural roads and motorways with a 110 km/h speed limit, while also clear impacts are found for urban roads. Again the results indicate that ISA has limited impact on 130 km roads - most likely because most road users find a 130 km speed limit high enough - an attitude, which is also found in the other Danish ISA project "*Pay as You Speed*".

The main results are statistically significant but they are only based on the first 1½ months with activated ISA equipment, and so far it seems that the drivers improve their behaviour regarding speed.

Based on these primary data it has been calculated that the average increase in transportation time with regard to the ISA system is as low as 9:51 minutes per vehicle per week. According to Danish socio-economic estimations the weekly expenses regarding increased transportation time per vehicle is 6.9 €.

VII. Acknowledgments

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HOW INTELLIGENT SPEED ADAPTATION AFFECTS COMPANY DRIVERS' ATTITUDES TO TRAFFIC RELATED ISSUES

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ABSTRACT

A Danish Intelligent Speed Adaptation trial with company cars was concluded in November 2008. It included 26 cars and 51 non-voluntary drivers. Results presented here are regarding attitudes to behaviour in traffic and to Intelligent Speed Adaptation. In general the trial has increased the drivers' awareness of speed limits but hardly changed the drivers' attitude to what constitutes dangerous behaviour in traffic. Further, ISA was assessed as more positive for company cars than for private cars. Moreover, respondents from this trial were more aware of risk in traffic than were young drivers in another Danish Intelligent Speed Adaptation trial.

KEYWORDS

Intelligent Speed Adaptation, Driving speed, Attitudes, Traffic, Road Safety, Attitudes, Traffic Safety, White van driving

BACKGROUND

Road safety is one of the world's main causes of loss of years of life. In 2004 it was estimated that more than 1.2 million people died because of poor road safety [1]. The European Commission has set an ambitious goal to mitigate this problem. The goal is a reduction of road fatalities by 50% in 2010 compared to the situation in 2001. Nevertheless, in 2005 only a reduction of 17% was reached and it became clear that new tools must be introduced to reach the goal. In this context, Intelligent Transport Systems (ITS) and especially Intelligent Speed Adaptation (ISA) could be key tools in reaching the goal [2]. ISA means equipment in a car which compares the current speed with the current speed limit and gives feedback to the driver if speeding. Various forms of response can be given if speeding occurs: There may be a visual and/or auditory response in case of violations, and/or a display may show the speed limit. Additionally, violations can be logged on an on-board computer. Finally, the accelerator pedal may give resistance (heavy accelerator pedal) or even make it impossible to violate speed limits (hard accelerator pedal). These different types of ISA systems can be categorized as informative, advisory, recording, or intervening systems [2].

Commercial drivers have a poor reputation among other road users due to their behaviour, and are notably over-represented in traffic accidents. A new Danish study has e.g. concluded that commercial drivers are approx. 125% more exposed to road fatalities or severe injuries than are drivers in private cars [3]. Moreover, many companies have recently formulated policies regarding safety, environment, etc. Consequently, ISA could be a suitable solution for the companies to fulfil their stated goals.

In a number of countries, ISA trials with company cars have been carried out in the last decade with significant results. The Australian *TAC Safecar* project, which was carried out from 2003 to 2005, included 15 company cars and 23 voluntary participating drivers. This involved an advisory and intervening ISA system which consisted of a display showing the speed limit if speeding and a heavy accelerator pedal if speeding continued. The main results were a reduction by up to 2.7 km/h for the 85 percentile speed, and driving time with speeding by more than 5 km/h was reduced by up to 57% [4]. Also, in Stockholm, Sweden an ISA project with 20 public cars and a total of 130 drivers was carried out from 2003 to 2005. The highest effect here was found for rural roads with a speed reduction of up to 2 km/h. On motorways the effect was smaller. This trial involved an intervening ISA system with a heavy accelerator pedal [5]. Further a Belgian ISA trial with both private and commercial vehicles was carried out in the City of Ghent. 14 company cars were involved in this study. No separate results were given for company cars. However, a reduction of up to 2.5 km/h was found for the 85% percentile speed for all cars. The ISA system used in the trial was similar to the one used in Sweden [6]. So far ISA in company cars has shown significant results.

An ISA trial with incentives for company drivers

In the Danish ISA trial *ISA Commercial* (ISA C), ISA was tested with non-voluntary company drivers. In addition to an informative and advisory function, the ISA system had an incentive function based on recording ISA, which consisted of penalty points if a driver violated the speed limit. In this paper the non-voluntary professional drivers' attitude to ISA and road safety topics in general are studied.

ISA C was carried out in cooperation between Vejle Municipality and Aalborg University and included 26 company cars and 51 drivers in total. The cars belonged in six companies with 1-5 vehicles in each company. In most companies, the participation was decided after discussions among the drivers, who were mainly positive towards the trial beforehand. In one company, the decision was taken without involvement of the drivers, who were of course less positive towards the trial. The trial was finalized in November 2008. It was generally based on the same technology as in the *Pay As You Speed* ISA trial (PAYS) [7]. However, there were some differences, and a brief description of the ISA system follows here.

In each car an "On Board Unit" (OBU) was installed. It consisted of:

- A GPS/GPRS unit with a memory card on which the digital speed map was stored,
- a display with a loudspeaker. The display showed the speed limit and any penalty points. The loudspeaker was used for verbal warnings in case of speeding, and
- a 'key reader' which could read the drivers' unique key ID and hence distinguish between several drivers' behaviour in the same car.

Based on a GPS signal the position was matched onto the speed limit map. This limit was shown in the display and compared with the car's speed. If the speed limit was exceeded by more than 5 km/h, the driver received a verbal warning in a female voice such as e.g.; *'50 – you are driving too fast*'. The warnings were repeated every sixth second until the speed was reduced to under the speed limit + 5 km/h. The third and subsequent warnings were associated with penalty points. The number of penalty points per warning depended progressively on the level of speeding. Moreover, each driver had access to a web page which showed all received penalty points.

During the first 1.5 months, the ISA equipment was inactive albeit collecting 'normal' behaviour among the drivers - a 'baseline period'. After this, ISA was activated. The number of received penalty points per driver was summarized and compared with the driven distance once a month. The driver with the fewest penalty points per driven distance was announced as the driver of the month and received a small present worth app. 40 €. After approx. 12 months with ISA activated, the trial stopped and the 10 drivers with virtually no penalty points received a GPS navigator for their private car as a reward. Data collected during the trial consisted of a recording of the driving for each driver based on GPS data. Also, the drivers' attitudes to traffic related issues were collected by two web-based questionnaires.

Recorded driving data from the full trial period have not yet been analysed completely. However, preliminary results based on the behaviour in the 'baseline period' compared with the behaviour in the first 1.5 months with ISA activated have shown remarkable results (see table 1) [8].

Table 1. The proportion of the driven distance at more than 5 km/h above the speed limit

	Speed limit (km/h)				
	50	70	80	110	130
Baseline period	18.7%	15.2%	18.9%	25.5%	5.0%
ISA activated	7.4%	5.1%	4.7%	6.6%	1.3%
Reduction	11.3%	10.1%	14.2%	18.9%	3.7%
p-value	0.000	0.000	0.000	0.016	0.290

Based on these data, speeding was reduced significantly on all analysed road types except on motorways with a 130 km/h speed limit where almost no speeding occurred anyway.

The effect from ISA was significant, but how did the drivers review their experiences with the system, and what were their attitudes to behaviour in traffic generally? Moreover, how has ISA affected these attitudes? The large-scale Swedish trials in which private car owners participated concluded that a substantial part of the drivers would like to keep the ISA equipment after the end of the trial and that they became more positive towards ISA in general [9]. In the TAC Safecar trial, increased discontent with the system was indicated [10].

METHODS

Research design data and statistical analyses

Data were extracted from two web-based questionnaires. One questionnaire was filled in during the 'baseline period', while the other was filled in when the drivers had driven with ISA activated for approx. one year. These are subsequently mentioned as 'baseline' and

‘ISA’, respectively. Although the drivers were forced to participate in the trial because ISA was installed in their company car, the questionnaires were filled in voluntarily. The two questionnaires were almost identical, so any effect from ISA would be measurable. In total, 51 drivers were equipped with a key ID, and 40 of them filled in the first questionnaire (baseline). The number of respondents in the second questionnaire was too low after the first deadline, and a small reward was subsequently offered to all respondents to increase the number. However, the second questionnaire was only filled in by 23 drivers (ISA). Of these 23, two were ‘new’ and had not filled in the first one. Consequently, the analyses made here consist of feedback from 21 drivers. Four of them were women. These drivers are subsequently denoted as ‘respondents’.

The questions used in this trial were very similar to the ones used in the PAYS trial. Therefore, it is possible to compare results from ISA C with the ones from PAYS where suitable. Results from PAYS are only shown in figures if they differ markedly from the ISA C results. In addition, it is notable that the groups of questions used are similar to the ones used in most new ISA trials [11]. The first questionnaire included a number of background questions such as age, gender, education and car use. Also, questions related to driving style, attitudes to driving style, safe driving, driving speed, speed limits, and risky traffic behaviour were included. Further, any differences between driving behaviour in private and in company cars were expounded. Moreover, the drivers were asked about their attitudes to a number of ISA systems, including the one they tried in ISA C. The questionnaires were sent to the respondents by e-mail. Each questionnaire took 15 to 20 minutes to fill in and consisted of some 90 to 125 questions, depending on some answers which resulted in additional questions. To keep the results from the trial short and clear and to deal with the limited space available, only selected results are presented here. Moreover, regarding a number of topics, the respondents were asked about their behaviour in both private and company cars. In many cases, the results were almost similar for the two types of vehicles. Therefore, results regarding driving in private cars are only included in a few cases. Using the advantages of web-based questionnaires, the respondents were provided with a continuous scale without visible values for indication of their attitudes to most of the questions. These scales have a hidden scale and were made as two types: one ranging from -200 to +200 in bipolar questions in terms of how much respondents agreed or disagreed with a statement, and one ranging from 0 to 400 depending on e.g. how often they speed (see Figure 1).

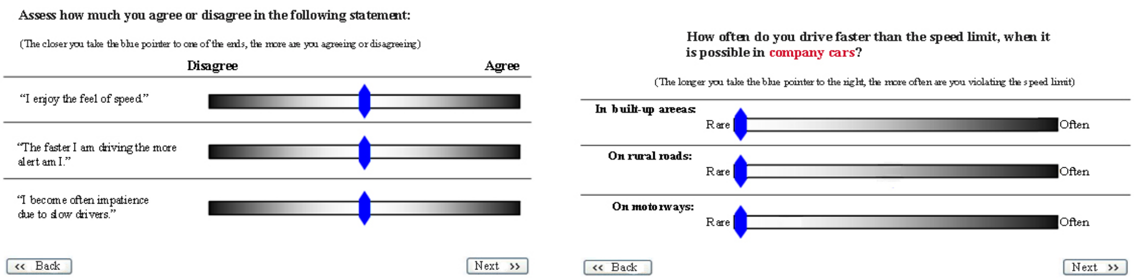

Figure 1. Examples of the two types of questions

A paired t-test was used to study differences between the baseline and ISA for various variables. Regarding e.g. the respondents’ attitudes to speeding in built-up areas, the differences for each respondent in the ‘baseline’ and ‘ISA’ were calculated. This resulted in up to 21 observed differences, and then a standard t-test was applied to test whether the theoretical mean of these differences was significantly different from zero. P-values below 0.05 are assessed to be of statistical significance, while p-values between 0.05 and 0.10 are assessed as likely to be of statistical significance.

RESULTS

Personal data

The participating respondents were between 24 and 61 years old when the trial started. The mean age was 44. 76% had one or several children. All had obtained their driving licence before they were 21, so most of them were experienced drivers. Their assessed driving in company cars differs widely, from 600 km to 34,800 km per year, and some 75% of the drivers answered that they drove between 10,000 and 15,000 km per year.

Attitude to and occurrence of speeding

The drivers' attitudes to risk in traffic depending on the road types in 'baseline' and 'ISA' are shown in Figure 2. Results marked with an oval indicate that the change is of statistical/likely to be of statistical significance.

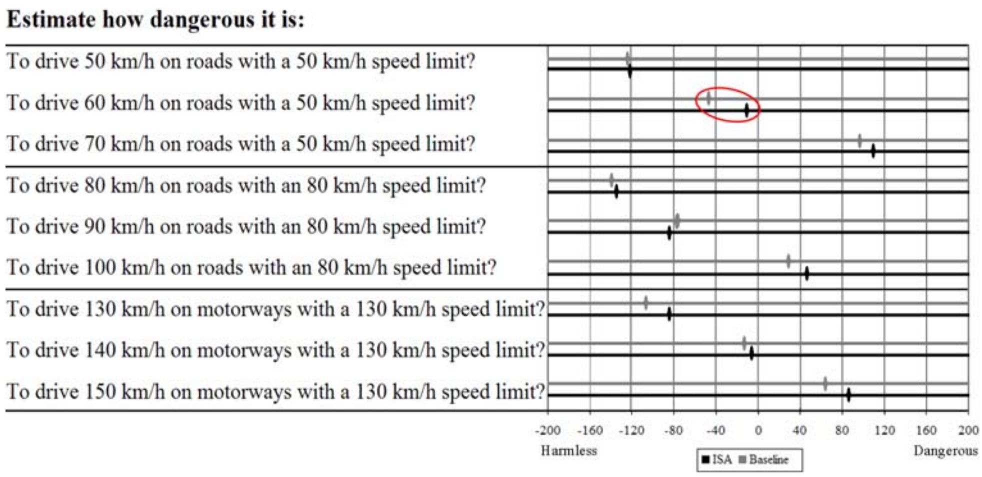

Figure 2. Respondents' attitudes to speed and risk on different road types

The Danish speed limit in built-up areas is 50 km/h, in rural areas it is 80 km/h, and on motorways it is 130 km/h, unless other speed limits are stated locally. In general the respondents found that increased speed results in higher danger. However, regardless of road type, they found a 10 km/h violation of the speed limit harmless rather than dangerous. Serious speeding by 20 km/h was assessed as somewhat dangerous, most dangerous on roads in built-up areas, and least dangerous on roads in rural areas. The only significant change due to ISA was regarding moderate speeding (10 km/h) on roads in built-up areas (p=0.041). These attitudes corresponded well with the attitude among voluntary participants in other Danish ISA trials as well as with Danish drivers who had never participated in an ISA trial [11,12]. In the TAC Safecar trial speed violations by 10 km/h were assessed as dangerous while the ones by 20 km/h were assessed as very dangerous [10]. In general the Australian participants found that speeding is more dangerous than did the Danish participants. The lowest acceptance of posted speed limits was for the rural roads. This result is alarming, because this is where the majority of severe road accidents occur in Denmark [13]. The respondents were also asked about their preferred speed limits on roads in built-up areas, roads in rural areas, and on motorways. Based on the mean results, these were approx. 50, 86, and 125 km/h for the three road types, respectively (not shown). So their feeling of danger corresponds well with the respondents' proposed speed limits. They assessed the limit in built-up areas as suitable, while it should be increased somewhat on rural roads and reduced to a similar extent on motorways. These results are somewhat identical with the ones found in the Belgian trial, where the respondents stated that they speeded the most on rural road and less in urban roads. Moreover, they felt that the speed limits in general were acceptable [14].

The respondents assessed that they speed quite rarely regardless of if they were driving in built-up areas, rural areas, or on motorways. In private cars the respondents stated that they speed least on roads in built-up areas, while they speed the least on motorways when driving company cars. No changes in attitudes due to the activation of ISA were significant. The discrepancy with the results in Figure 2 may be because small violations of a speed limit might not perceived as 'real' speeding in the results in Figure 3.

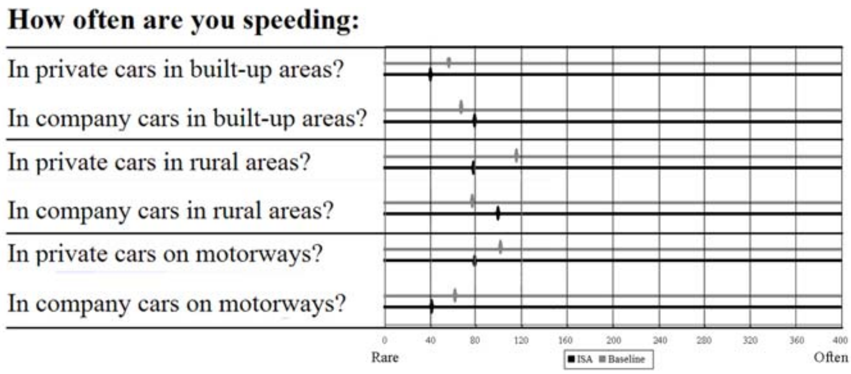

Figure 3. Respondents' assessment of how often they speed in company cars and private cars, respectively

Attitudes to different types of and reasons for risk related behaviour

The two most important reasons for speeding appear in Table 2. Both in the baseline and ISA period it was lack of awareness of the speed and a desire to follow the flow of traffic. Pressure from others cars was in the baseline a minor reason for speeding, but with ISA the proportion increased as expected. Intention to speed is more rarely as reasons for speeding and did not change. The awareness of the speed limits decreased from baseline to ISA. One can wonder about this result, because the respondents in the ISA period got continuous information about the speed limit contrary to in the baseline period where they only had information from the speed limit signs placed on the road. Finally their urge to speed dropped from baseline to ISA. It was probably because in the ISA period they knew that that speeding was not possible without getting penalty points. However, none of these changes were of statistical significance. In the TAC Safecar trial, the respondent stated that the most important reasons for speeding were lack of awareness of the speed and unawareness regarding the speed limit. A desire about to follow the traffic was only rare the case [10].

Table 2. Respondents' two most important reasons for speeding

	Baseline	ISA
	Proportion	
I wish to follow the traffic.	62%	57%
I am not aware of my speed.	67%	52%
I feel pressure from other cars.	14%	29%
I intend to speed.	19%	19%
I am not aware of speed limit.	19%	38%
I feel an urge to speed.	19%	5%

The reasons for speeding were several, and so were the various risk-related activities. Figure 4 shows respondents' attitudes to risky behaviour.

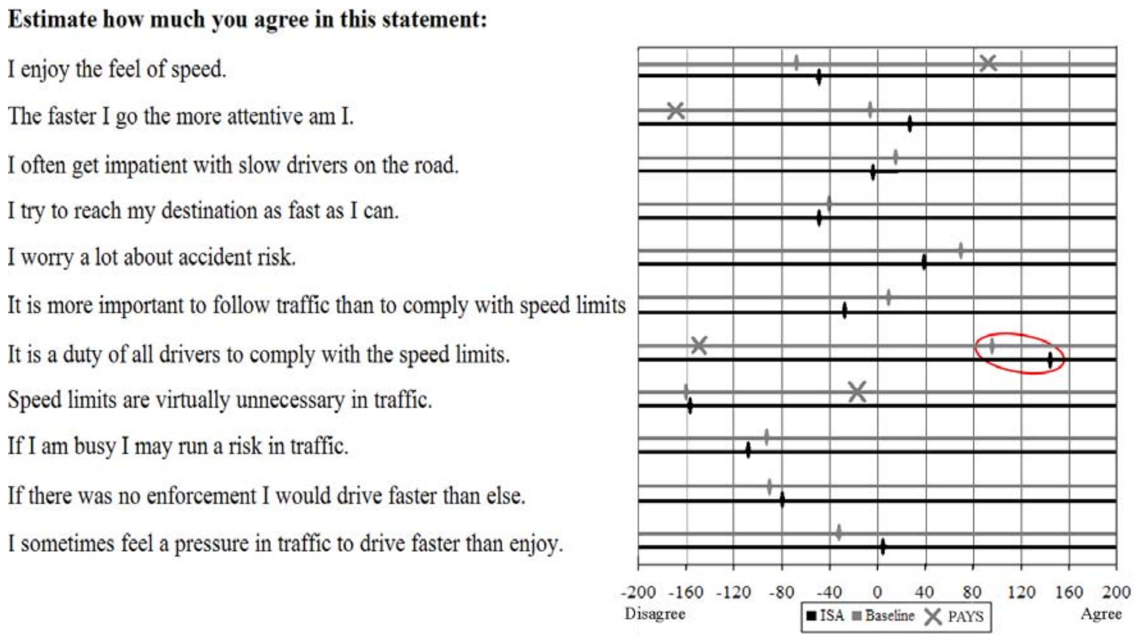

Figure 4. Respondents' attitudes to a various statements regarding risky behaviour

Respondents generally disagreed with the following statements:

- enjoying the feeling of speed,
- lack of enforcement would make them speed more,
- if busy they were prepared to take risks,
- they try to reach their destinations as soon as possible, and
- speed limits are unnecessary in traffic.

Respondents neither agreed nor disagreed on the following issues:

- feeling of pressure from the car behind,
- it is more important to follow the traffic than the speed limits,
- they would often become impatient due to slow drivers, and

- increased speed results in increased awareness.

Respondents agreed with these statements:
- they worried much about the risk of accidents, and
- it is a duty of all drivers to comply with speed limits.

When these results are compared with the ones found in other ISA trials, there are some noticeable differences. The respondents in ISA C stated that speed did not result in enjoyment. The drivers in the Belgian ISA trial were also disagreeing in this statement, while the drivers in PAYS stated the opposite [11,14]. On the other hand, the ISA C respondents were almost neutral regarding higher speeds resulting in higher awareness, while PAYS showed significant disagreement with this statement. Also differences were found regarding the necessity of speed limits and the duty to comply with them, which the ISA C drivers found much more important than, did the PAYS drivers. Furthermore, ISA C resulted in a significant increased agreement on this statement (p=0.012), so it seems that their safety awareness has increased somewhat. The reasons for these noticeable differences are probably that the PAYS drivers were younger, less experienced and somewhat blind to risks related to speeding. These characteristics are well known for young drivers and could explain some of their high over-representation in the accidents statistics.

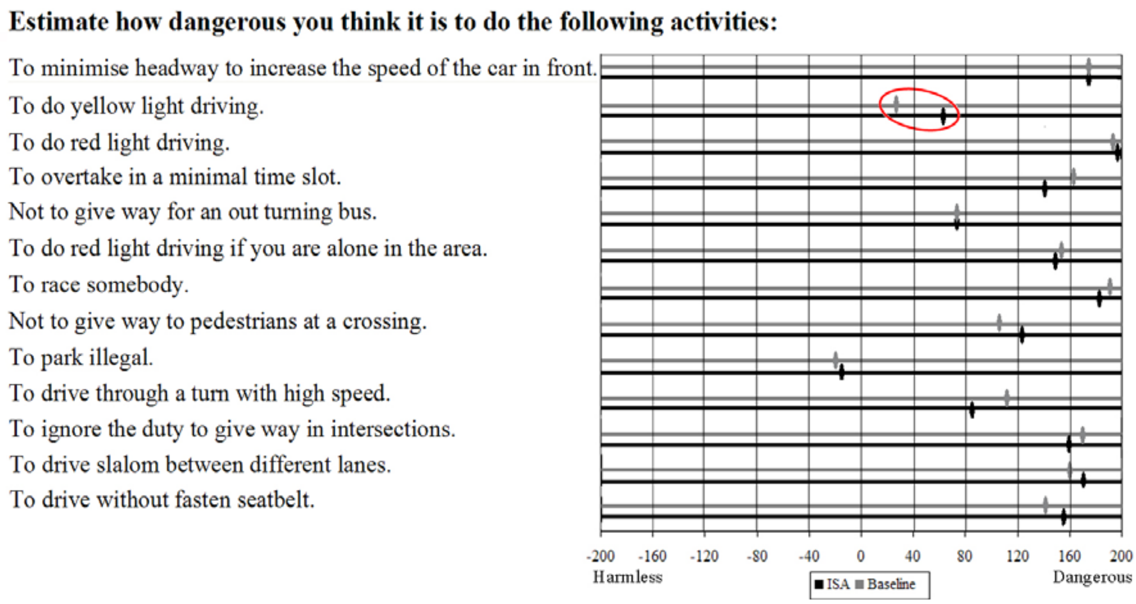

Figure 5. Respondents' estimated level of danger in connection with activities in traffic

Moreover, the respondents have answered questions about how dangerous a number of risk-related activities in road traffic are (see Figure 5). A hypothesis could be that ISA would have increased respondents' risk awareness. However, this is not supported by the feedback from respondents. In general, respondents' assessed danger of risk-related activities only changed minimally after the introduction of ISA. Only yellow-light driving tended to change significantly towards a more dangerous assessment (p=0.0849). Therefore, it can be concluded that ISA C did not change respondents' view of what constitutes dangerous behaviour in traffic.

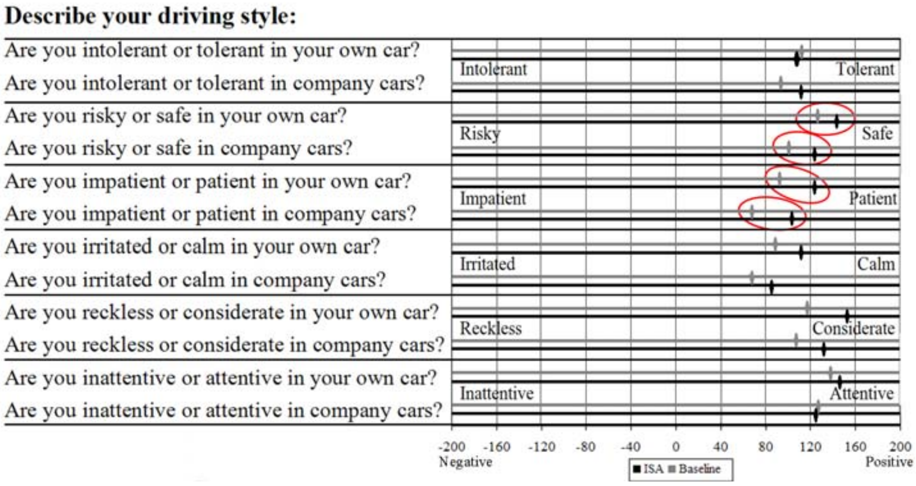

Figure 6. Respondents' assessment of their behaviour in company and private cars, respectively

As shown in Figure 6, respondents stated that their driving behaviour was positive rather than negative. Based on the summarised values for each respondent, ISA resulted in significantly better behaviour (p=0.0142), but also significant changes regarding other statements are found. Patience increased for private and for company cars (p=0.0065 and p=0.0167, respectively). Also, drivers' behaviour became safer with ISA (p=0.0203 and p=0.0395, respectively). Further, consideration and calmness in private cars were likely to increase significantly (p=0.0638 and p=0.0934, respectively). In general, the results correspond well with the PAYS results. However, the respondents in ISA C stated that they were slightly more tolerant and calm than did the ones in PAYS - maybe due to the higher age group in ISA C. Another thing that appears from these data is that for all objectives, partly with the exception of 'Tolerant' vs. 'Intolerant', the respondent stated that their behaviour was more negative when driving in company car than in private car. This points towards the same problems regarding safety and company cars as stated in the first section.

Attitudes to ISA

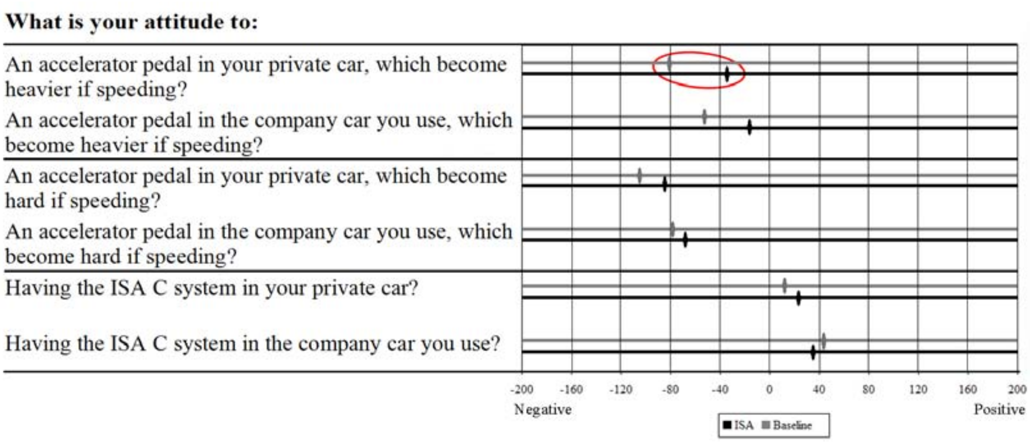

Figure 7. Respondents' attitude to different ISA systems in company cars and private cars, respectively

Respondents' attitudes to different ISA systems appear in Figure 7. When asked about their attitude to ISA equipment in general, and to the ISA C equipment in particular, they were cautiously positive towards driving with the ISA C equipment both in private and company cars. Respondents' attitudes to the heavy and hard accelerator pedal were, despite a decrease in negativity during the trial, generally rather negative. As regards a heavy accelerator pedal, the changes towards a more positive attitude tended to be significant for private cars, while it almost tended to be so for company cars (p=0.0901 and p=0.1278, respectively). These results correspond reasonably well to the results from PAYS. What is also noteworthy is that the respondents were in general slightly more positive towards ISA in company cars than in their private cars, irrespective of the type of ISA. It is also noteworthy that the respondents in general were slightly more positive towards ISA in company cars than in private cars, irrespective of the type of ISA. It also corresponds well to the respondents' assessment that their attitudes when driving in company cars were slightly more negative than when driving in private cars. These results show both a bigger need and a bigger acceptance of ISA in company cars than they do in private cars. In Belgium, it was found that commercial drivers were slightly negative to ISA (heavy accelerator pedal) while the private drivers were clear positive [14]. In ISA C the drivers were also mainly negative, but they were less negative regarding ISA in commercial vehicles. Moreover in the Australian trial, the respondent stated that they were positive to a heavy accelerator pedal while they were negative to a hard one [10].

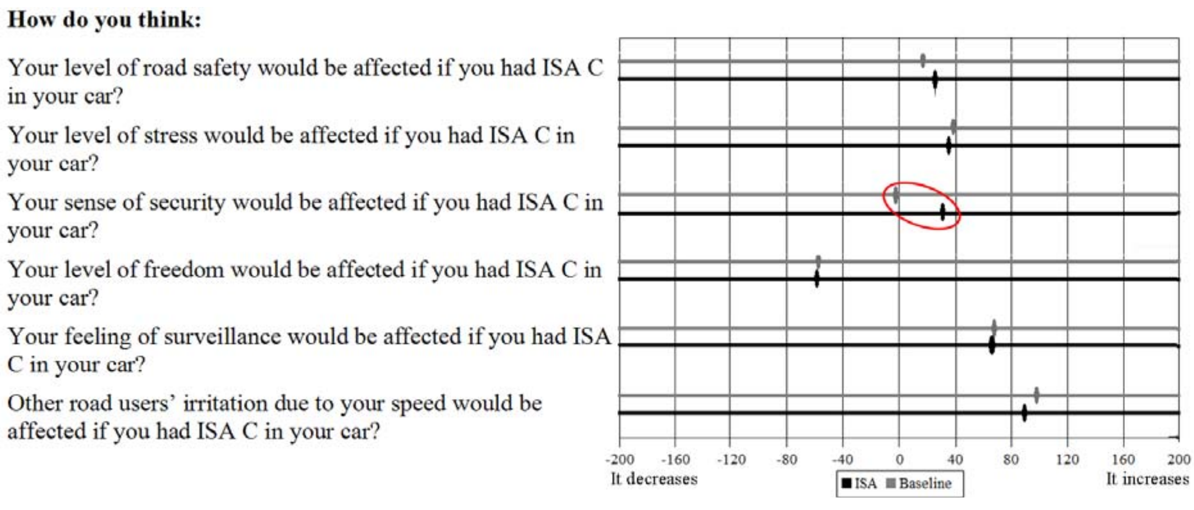

Figure 8. Respondents' attitude to the ISA C equipment

Respondents' attitudes to how the ISA C system would affect their driving experience are expanded in Figure 8. In ISA C the level of safety due to ISA was assessed as slightly positive and almost stable from before to after trying ISA while in the Swedish trials it decreased substantial after ISA was tried [9]. Both irritation from other road users due to ISA and the expected feeling of surveillance were assessed as increased due to ISA. Freedom on the road was assessed as reduced due to ISA, while the sense of security was assessed as slightly positive. The level of stress remained unchanged due to ISA. In the TAC Safecar trial, the large-scale Swedish trial and a Swedish trial with commercial vehicles the level of stress or irritation was assessed a good deal bigger due to ISA [5,9,10]. It hardly changed in ISA C. The sense of security while driving was significantly higher after activation of ISA (p=0.0254). It is also noticeable that except regarding the feeling of freedom while driving, attitudes to the ISA C system were positive rather than negative. The same result was found in the TAC Safecar trial, but here the respondents became markedly less satisfied with ISA after the trial [10]. Opposite to this, driver attitudes in ISA C under ISA conditions did neither differ significantly from the ones found in PAYS nor from the ones in baseline.

DISCUSSION, SUMMARY, AND CONCLUSION

One might perhaps question if the respondents are representative of the average company car driver. However, it is known that not all the drivers were keen on participating but were obliged to do so. Furthermore, one could ask if there is bias among the respondents towards the most positive part of the drivers in the participant companies. Probably, there is such a bias, but the small reward to respondents of the second questionnaire raised the respondent rate and has resulted in more mostly 'negative' respondents than else. However, irrespective of whether or not there is bias, it is reasonable to assume that any bias is significantly lower than for other ISA trials based on voluntary participation. Results from the Danish ISA trial PAYS have e.g. shown that voluntarily participating drivers sped less and were more positive to ISA beforehand than the average driver [11].

ISA C with 26 vehicles and 51 drivers in total was carried out in 2007 to 2008, and the results in this paper are concerned the drivers' attitude to ISA and road safety-related issues in general. The drivers were non-voluntary and some of them were negative towards ISA. In addition to informative and advisory functions, ISA was supplied with an incentive function consisting of penalty points if speeding occurred. Data collected during the trial consist of driving data based on GPS data and two web-based questionnaires regarding drivers' attitudes to traffic-related issues.

ISA seems to have resulted in increased awareness of danger associated with speeding, but it has only changed significantly as regards roads in built-up areas. This result corresponds well with a high acceptance of speed limits here. It was also stated that ISA did not result in significant changes in the reasons for speeding even though pressure from other cars increased and the urge to speed decreased. However, the attitude to complying with speed limits increased significantly among the respondents. On the other hand, except as regards yellow-light driving, ISA did not change drivers' awareness of danger in risky situations. Moreover, when respondents were asked about their own driving style, they assessed it as safer after trying ISA, but they also stated that their behaviour was better in their private car than in their company car. Acceptance of ISA changed only slightly but was, however, regarded quite positively. In general, the acceptance of ISA in company cars was higher than in private cars. ISA also resulted in a feeling of a higher sense of security, while safety, stress, other road users' irritation, and freedom hardly differed from the expected levels. Also, if comparing the results found in ISA C with the Danish PAYS trial involving young car owners, it is evident that the respondents in ISA C were markedly less keen on speeding and more aware of the danger in traffic than were the young. In general the drivers in ISA C were somewhat in between the drivers in PAYS who were rather risky in their attitudes, and the respondents in other trials. It might be so, because the participants in ISA C were older than in PAYS and not all were voluntary participating opposite to participants in the other trials.

Overall, ISA C has increased drivers' awareness of speed limits but has not significantly changed drivers' attitude to dangerous behaviour in traffic. Moreover, ISA was assessed as more positive for company cars than for private cars.

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