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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

[1] Submitted March 25, 2008

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.

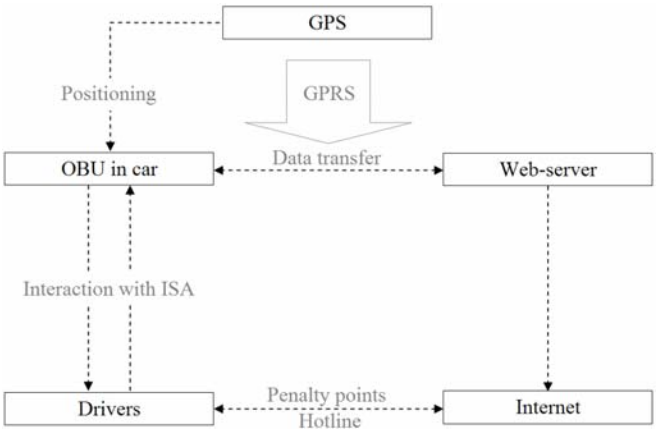
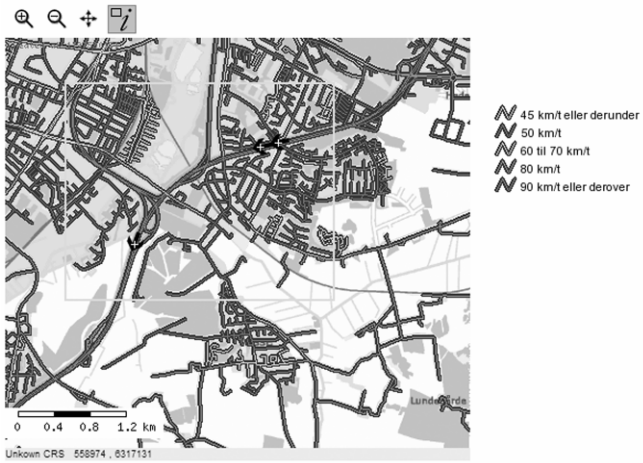


Fig. 1. The flow in the ISA.

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.



Hastighedsoverskridelser

Hastighedsgrænse	Bilens Hastighed	Antal point	Dato og tid	Overskridelse nr.	Tur nr.
110	126	1	05.10.06 kl. 08:27:46	690	494
110	119	1	05.10.06 kl. 08:27:52	691	494
110	119	1	05.10.06 kl. 08:28:50	692	494

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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