Pay as You Speed, ISA with incentives for not speeding: Results and interpretation of speed data

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A B S T R A C T

To simulate a market introduction of Intelligent Speed Adaptation (ISA) and to study the effect of a Pay as You Speed (PAYS) concept, a field trial with 153 drivers was conducted during 2007–2009. The participants drove under PAYS conditions for a shorter or a longer period. The PAYS concept consisted of informative ISA linked with economic incentive for not speeding, measured through automatic count of penalty points whenever the speed limit was exceeded. The full incentive was set to 30% of a participant’s insurance premium. The participants were exposed to different treatments, with and without incentive crossed with informative ISA present or absent. The results showed that ISA is an efficient tool for reducing speeding particularly on rural roads. The analysis of speed data demonstrated that the proportion of distance driven above the speed where the ISA equipment responded (PDA) was a sensitive measure for reflecting the effect of ISA, whereas mean free flow speed and the 85th percentile speed, were less sensitive to ISA effects. The PDA increased a little over time but still remained at a low level; however, when ISA was turned off, the participants’ speeding relapsed to the baseline level. Both informative ISA and incentive ISA reduced the PDA, but there was no statistically significant interaction. Informative reduced it more than the incentive.

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1. Introduction

1.1. Incentive ISA

Over the past two decades, several studies have reported positive effects on drivers’ speed by installing Intelligent Speed Adaptation (ISA) equipment (see Carsten et al., 2008; Vlassenroot et al., 2007; Regan et al., 2006; Warner, 2006; Várhelyi et al., 2004; Biding and Lind, 2002 for ISA studies). The previous studies have provided proof of concept and contributed to development and refinement of the technologies that have pushed ISA forward from being a bright, though brittle idea to being a mature safety technology close to market introduction. A few studies have tested various forms of recording ISA. Peltola et al. (2004) tested recording ISA on taxi drivers, using log data to give personal feedback to drivers about their speeding. In Belonitor (2009) participants could earn points by complying with speed limits and subsequently exchange the reward points for rewards. The rewards were indoor or outdoor experiences: active, cultural, sporting or simply relaxing. Participants also competed with each other every month to win the First Prize: a reward of 500 Euros. Hultkrantz and Lindberg (2009) gave participants a fixed monthly bonus which was subsequently reduced in proportion to the participants’ speeding.

1.2. Pay as You Speed (PAYS), the General Idea

The study reported in this article, the Danish “Pay as You Speed” (PAYS) project, was based on the positive experience of previous ISA studies including the Danish INFATI project, which was a predecessor of PAYS (Lahrmann et al., 2001). However, the PAYS project was different from previous studies in its scope in that it was planned as a large-scale simulation of a market introduction of ISA equipment for private cars. With this perspective it was an obvious idea to combine the more attractive but less efficient (Päätalo et al., 2001; Dahlstedt, 2002) informative or advisory ISA equipment (Carsten and Tate, 2005) with a conditional discount on car insurance premiums. The cooperating partner, the insurance company “Topdanmark”, set a 30% discount rate for participants in the PAYS project. The project name: “Pay as You Speed” refers to the close linkage of three factors: ISA equipment, driver behaviour and incentive for not speeding. From a market introduction perspective, young drivers were an obvious target group. Due to their high accident rate, young drivers pay high car insurance premiums and would therefore gain more than other drivers from having
ISA installed in their private cars on PAYS conditions – provided of course that they would actually refrain from speeding. We hypothesized that if young drivers achieved good speed behaviour by driving with ISA then they would retain good speed behaviour even with no ISA in their car.

2. Method

2.1. Concepts and measures of driving speed in ISA studies

Despite the fact that the very purpose of ISA equipment is to prevent car drivers from exceeding the speed limit, most ISA studies have reported another measure: reduction in mean speed and standard deviation as effects of driving with ISA (see Warner, 2006 for a review). More relevant measures have been introduced, including the number of speed violations (De Ward and Brookhuis, 1997; Berg et al., 2008) or the time or distance driven at a speed above the speed limit (Regan et al., 2006; Warner and Åberg, 2007; Vlassenroot et al., 2007; Carsten et al., 2008), however, there is yet no common standard measure for describing the effect of ISA equipment on driving speed. Obviously, conventional speed measures, known from traffic engineering and traffic safety research (Nilsson, 2004; Elvik, 2005), are not convenient for assessing the effect of ISA equipment on speed. In the next few paragraphs we discuss the insufficiency of conventional speed measures in assessing effects of ISA and we propose more convenient standard measures for describing the effect of ISA on speed and speeding, in detail and with accuracy.

2.1.1. Different terms to describe speed observations

In previous studies, the effect of ISA has been described by observing changes in the participants’ speed at different locations of the road such as locations with different speed limits (Várhelyi et al., 2004). The method copies the normal cross-sectional speed measurement method traditionally used in traffic engineering to describe traffic safety and congestion on roads; this kind of measurement is often referred to as point speed. Most frequently, point speed is simply described by its mean value and standard deviation. The 85th percentile of the point speed observations and the percentage of speeds above the speed limit or of the speed limit +10 km/h are also conventional descriptions of levels of speed in a cross section of a road (Lahrmann and Leleur, 1995). This tradition is due to the lack of methods other than cross-section measurement to measure speed. With log data from GPS receivers, however, this situation has changed. GPS receivers now enable us to log the position, the speed and the course every second and to get a detailed track of the movement of the individual car and thereby obtain an excellent dataset to describe the effect of ISA. But how can these observations be used to describe the effect? Some studies have based their calculations of the effect on the changes in these time-based observations (Hultkrantz and Lindberg, 2009; Regan et al., 2006; Biding and Lind, 2002). The effect is thus calculated in proportion to the time the car stayed on the road network. In describing traffic safety, time is not normally used as a unit—the normal unit is a length unit (Lahrmann and Leleur, 1995), but because our observations are time based we must use a method where we let the time-based observations count in proportion to the distance travelled between two observations. Mean speed of traffic across a road section with n speed observations should be calculated as follows:

\[ \bar{v} = \frac{\sum_{i=1}^{n} v_i \times l_i}{\sum_{i=1}^{n} l_i} \]  

where \( v_i \) is speed and \( l_i \) is the distance travelled with the speed \( v_i \).

Our “mean” is a weighted mean where each speed measurement \( v_i \) is weighted by the corresponding distance \( l_i \).

This method was also used in other ISA projects (Hattem and Mazureck, 2006; Carsten et al., 2008; Berg et al., 2008).

The next question is whether all speed observations are relevant to the assessment of possible ISA effects. It may be argued that only speed observations where the driver’s speed choice is not limited by a car ahead, a curve or a signalized intersection should be included in the assessment and thus in the calculation of the above-mentioned average speed and 85th percentile. But as the log files do not contain that kind of observation, we propose the next best solution which is to exclude speed data from the analysis in cases where speed choice can reasonably be assumed not to be a free choice. In the PAYS project we chose to exclude all speed observations considerably below the speed limit with regard to the dependence between speed and speed limit (see Table 1). The values in Table 1 are estimates based on our educated estimate about the lowest level of speed that a driver would select unless speed was influenced by external factors. These speeds were used in the PAYS project for calculating free flow speed (FFS). In the following sections we use the term mean free flow speed (MFFS). The MFFS is calculated using (1) and as such the MFFS is not the usual arithmetic mean but a weighted mean. The 85th percentile speed is calculated in the same way and is termed 85 free flow speed (85FFS).

2.1.2. Proportion of distance driven above the speed limit (PDA)

The purpose of ISA equipment is to prevent drivers from speeding rather than to reduce speed in general. An accurate and precise measure of the effect of ISA equipment is therefore the proportion of distance driven at a speed above the ISA activating level as compared to the same measure when driving without ISA. With logged data from a GPS receiver the proportion of distance driven above a specific speed level is easy to calculate. The ISA system used in the PAYS project was programmed to play a voice message warning whenever the speed limit has been exceeded by more than 5 km/h (see Section 2.4). The proportion of distance above the speed limit + 5 km/h (PDA) is therefore used to describe the change in speed behaviour caused by ISA; for comparative purposes, though, we reported the effect also as change of mean free flow speed, standard deviation and 85th percentile of free flow speed.

2.2. Journey time

Another important measure of the effect of ISA equipment is the increase in journey time linked to driving with ISA. A possible increase in journey time caused by ISA is only due to a reduction in the distance driven above the speed limit, whereas a number of external factors other than ISA may still prevent a free speed choice, e.g. the time where the speed is limited by a car ahead may increase when ISA is off compared to the situation where ISA is on. The calculation of travel time should therefore include all observations regardless of the speed level observed. In the PAYS project the assessment of a possible increase in journey time was calculated per 100 km across all speed observations.

2.3. Impact on individual level

The impact of PAYS was calculated on an individual level meaning that the effect is calculated individually for each participant. Subsequently, the total effect was calculated by averaging the individual impacts, each individual driver thus counting equally, regardless of differences in their mileages in the study.

2.4. Field trial set-up

The ISA technology used in the PAYS project enabled surveillance of driving speed on the entire road network in Northern Jutland – 22,000 km. The on-board equipment was a dashboard
mounted display showing the speed limit continuously. If the posted speed limit was exceeded by more than 5 km/h, a female voice message would warn the driver. The voice message was repeated every 6 s and after the second message the ISA system started counting “penalty” points until the speed was back below the limit + 5 km/h. Any speeding during a trip was uploaded to a web server after the trip. The driver could check the penalty points on a personal web page. The total number of “penalty” points detected within a 6-month period was used for calculating the reduction in the participants’ 30% insurance discount for that period. Our hypothesis was that the information effect of the voice would decrease over time because the drivers would get used to the voice, whereas the “penalty” point effect would increase over time because the website statistics would make the drivers aware of their loss of bonus when speeding.

The original plan was to have ISA equipment installed for a three-year period in 300 private cars owned by drivers below 24 years of age given that young drivers have a high accident risk. We further hypothesized that ISA has an educating effect: if young car drivers adopt a good speed culture as young, they will continue this positive speed behaviour in their later car driving career. However, due to a low number of volunteers from the original target group, the age criterion was modified and ultimately abandoned. Thus, the PAYS project never reached 300 participants but ended up with a total of 153 participants of all ages. Unfortunately, the low number of participants resulted in early termination and therefore all participants had a shorter driving period than the 3 years planned. For a detailed description of the ISA equipment and the recruiting process see Lahrmann et al. (2011) in this issue.

The field trial was subdivided into 18 successive periods of 45 days. The very first period was a baseline in which the ISA system was actively logging data from the participants’ cars, but the participants did not receive any speed information from the system. As the PAYS project mixed informative ISA technology with incentive for not speeding, we subsequently investigated the impact of each of these two factors on participants’ speed during an experiment phase which consisted of three 45-day periods after the baseline period. During the experiment phase the aforementioned two PAYS factors, information and incentive, were crossed and each participant randomly assigned to one of four different groups (see Fig. 1): (1) a control group which continued as in the baseline period and whose speed was logged, but whose display was turned off and who received no penalty points and thus the full discount; (2) an incentive group whose display was likewise turned off, but who incurred penalty points when speeding and could access their personal webpage after a trip to see their points; (3) an information group whose display was turned on and who received information about speed limits and speeding, but who incurred no penalty points if speeding; (4) a combination group whose display was turned on and who received penalty points, i.e. a combination of information and incentive. The experiment phase consisted of three 45-day periods.

The experiment phase was followed by thirteen 45-day periods, the ISA phase, under conditions similar to the above-mentioned combination group. The last 45-day period was a post-baseline period equivalent to the baseline period, i.e. data was logged but no information or incentives were given (Fig. 2).

2.5. Procedure

The first on-board ISA unit was installed in June 2006 and the last in February 2008. By the autumn of 2008 the number of participants had decreased to just over 100. As this trend was expected to continue until the planned end of the project, PAYS was terminated early by 15th December 2008. The final 45-day period, from 1st November 2008 to 15th December 2008 served as the post-baseline period during which the display was turned off and the calculation of penalty points terminated; in line with the first baseline period only speed data logging continued in the post-baseline period. Thus, the PAYS field trial consisted of a maximum of eighteen 45-day periods: a baseline period, three experiment periods during which the participants were submitted to different treatments (see Fig. 3), a varying number of ISA periods driven under PAYS conditions, and a post-baseline period at the end of the project.

![Fig. 1. Participants divided into four groups with different driving condition in the experiment periods.](image1)

![Fig. 2. The four phases in field trials.](image2)
The number of ISA periods varied between participants depending on two factors: first, the time of project inclusion, and second, the participants’ choice to leave the project or to stay the full period. Eight participants were test pilots for the equipment and did not have a baseline period, 31 participants had technical problems with the equipment in the baseline period and these results were excluded from the analysis. Only 91 participants ended up with a post-baseline period and among those only 65 had participated in the first baseline period. Finally, and again due to technical problems, data from 7 participants was lost. Thus, speed data – for at least one period – were available for 146 out of a total of 153 participants. The participants’ project involvement is illustrated in Fig. 3. Each row in Fig. 3 represents one participant. Row length shows the total number of 45-day periods that a participant was involved in the project and the different row patterns show the number and type of periods during which speed data were available to participants.

2.6. Participants

The 146 drivers with logged data were comprised of 64% men and 36% women. Their ages ranged between 18 and 81 years with a mean age of 39. The proportion of young drivers under 29 was 44%. Their mean age was 24, while the mean age of the non-target group, i.e. drivers included after the change of inclusion criterion, was 51 (Table 2).

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Woman</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>18–24</td>
<td>20%</td>
<td>5%</td>
<td>25%</td>
</tr>
<tr>
<td>25–28</td>
<td>12%</td>
<td>7%</td>
<td>19%</td>
</tr>
<tr>
<td>29–38</td>
<td>7%</td>
<td>7%</td>
<td>13%</td>
</tr>
<tr>
<td>39–48</td>
<td>4%</td>
<td>5%</td>
<td>9%</td>
</tr>
<tr>
<td>49–58</td>
<td>10%</td>
<td>8%</td>
<td>18%</td>
</tr>
<tr>
<td>59–68</td>
<td>8%</td>
<td>3%</td>
<td>12%</td>
</tr>
<tr>
<td>69+</td>
<td>3%</td>
<td>0%</td>
<td>3%</td>
</tr>
<tr>
<td>No age</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Total</td>
<td>64%</td>
<td>36%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The mean speed measured on Danish roads in the PAYS project period by year and speed limit (Danish Speed Index).

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>121.1</td>
<td>122.2</td>
<td>122.3</td>
</tr>
<tr>
<td>110</td>
<td>116.0</td>
<td>117.7</td>
<td>117.1</td>
</tr>
<tr>
<td>80</td>
<td>85.5</td>
<td>87</td>
<td>87.3</td>
</tr>
<tr>
<td>50</td>
<td>51.3</td>
<td>51.7</td>
<td>51.7</td>
</tr>
</tbody>
</table>

3. Results

The ISA equipment logged the speed and the position of the individual car with a frequency of 1 Hz whenever the ignition was on. These data were uploaded through a GPRS phone to a database (see Lahrmann et al., 2011 in this issue for a description of the equipment and the logging procedure). At the end of the PAYS project the database contained 383 million sets of observations.

In Denmark the general speed limit in urban areas is 50 km/h. Some roads in urban areas have a speed limit below 50. The majority of those are traffic calmed roads, i.e. the construction of the road prevents cars from exceeding the speed limit – typically by means of humps. As a consequence, speed on these roads does not depend on the presence of ISA equipment. Data from roads having a speed limit below 50 was therefore excluded from the analysis. On all other roads the participants were logged for a total of 50,000 h. The total distance travelled during that period of time was 2.9 million kilometres. Travel distances ranged from 191 km to 71,000 km with an average distance of 20,000 km per participant.

Table 3 shows the general mean speed measured on Danish roads during the period of the PAYS project. As can be seen from the table, apart from 50 km/h roads, there was an overall increase in speed on Danish roads during the project period. This means that the assessment of the effects of ISA in the project may be a little conservative.

3.1. The experiment

The analysis in the experiment phases is based on a total travel distance of nearly 1 million kilometres.
3.1.1. Proportion of distance above speed limit plus 5 km/h

The graphs in Fig. 4 show proportion of distance above speed limit plus 5 km/h (PDA) in the experiment. Graphs are presented for the four groups for all roads, for 50 km/h roads and for 80 km/h roads.

We consider a statistical analysis of the effect of information, incentive and time on the PDA, where we perform a logit transform on the observed PDAs. The logit transform helps in fulfilling the assumptions of normality and variance homogeneity made below. Specifically, let \( r_i \) denote the PDA for the \( i \)th car for period \( t \), where \( t = 0 \) denotes the baseline period and \( t = 1, 2, 3 \) denotes the three experimental periods. The logit transformed PDA is then \( d_{it} = \ln(r_i/(1 - r_i)) \). Further, let \( j = 0 \). 1 correspond to no incentive and incentive, respectively, and let \( k = 0 \). 1 correspond to no information and information, respectively. Notice that since all cars are in the control state during the baseline we set \( i = j = 0 \) when \( t = 0 \) for all cars. We then consider the following random effects model

\[
d_{it} = m + a \cdot j + b \cdot k + c \cdot j \cdot k + p_t + u_i + \epsilon_{it}.
\]

Here and throughout this paper the \( u_i \)'s are independent zero mean normally distributed random effects and the \( \epsilon_{it} \)'s are independent and zero mean normally distributed error terms. In this model the intercept, \( m \), corresponds to the mean of the logit transformed MFFS for the control group. The parameters \( a \) and \( b \) are the main effects of information and incentive. Parameter \( c \) is the interaction effect between information and incentive. Finally, \( p_t \) is the effect of time, where \( p_0 = 0 \).

Considering the overall PDA across speed limits we find that there is a statistically significant effect for both information and incentive, but no statistically significant interaction. Furthermore, there is a statistically significant effect of time, but it implies no systematic increase or decrease in the PDA during the three experiment periods.

The estimated effects in a model where the interaction effect has been removed are as follows: \( a = -1.09, b = -0.75, p_1 = 0.25, p_2 = 0.28 \) and \( p_3 = 0.20 \). As it can be seen, both information and incentive reduces the overall PDA.

For both 50 km/h and 80 km/h roads the general pattern is the same as in the analysis of the overall PDA. Specifically, the effect of interaction between information and incentive is the only non-significant term in the model. The noteworthy difference between 50 km/h and 80 km/h roads is that for 80 km/h roads there seems to be a systematic increase in the PDA during the three experimental periods.

3.1.2. Mean free flow speed (MFFS)

In the analysis of the MFFS in Tables 4 and 5 each ISA group is considered separately. For each group let \( s_i \) denote the MFFS for \( i \)th car during period \( t = 0, 1, 2, 3 \), where \( t = 0 \) corresponds to the baseline period, and \( t = 1, 2, 3 \) corresponds to the three experimental periods. Furthermore, let \( k = 0 \), 1 correspond to baseline and experiment period, respectively. We analyse the data using the following model

\[
s_{it} = m + a \cdot k + b_t + u_i + \epsilon_{it}
\]

where we assume that \( b_0 = b_1 = 0 \). The term \( a \) can be interpreted as the effect of going from baseline to experiment. The \( b_t \) terms serve as a way to capture any change in the MFFS during the three experiment periods.

There is no statistically significant effect of time for any of the four groups on either 50 km/h or 80 km/h roads, i.e. we assume that \( b_t = 0 \) for \( t = 2, 3 \). Hence, there is no evidence that the effect of ISA, when looking at the MFFS, is changing during the experiment periods.

On 80 km/h roads only the combination and information groups show a statistically significant difference in the MFFS. In an analysis
Table 4
Mean free flow speed and standard deviation (km/h) on rural roads with 80 km/h speed limit divided between groups and the four 45-day periods: baseline, the three experiment periods and the total experiment period. The numbers inside the brackets are the (usual) sample standard deviation for the FFS observations.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
<th>Experiment 3</th>
<th>Experiments 1 + 2 + 3</th>
<th>Difference</th>
<th>BAS − EXP 1 + 2 + 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>78.7 (6.9)</td>
<td>77.5 (5.9)</td>
<td>77.7 (5.7)</td>
<td>77.8 (5.7)</td>
<td>77.7 (5.8)</td>
<td>−1.1*</td>
<td></td>
</tr>
<tr>
<td>Incentive</td>
<td>77.8 (6.5)</td>
<td>77.9 (6.4)</td>
<td>78.1 (6.5)</td>
<td>78.0 (6.5)</td>
<td>78.0 (6.5)</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>80.5 (7.8)</td>
<td>77.0 (5.2)</td>
<td>74.4 (5.2)</td>
<td>77.7 (5.5)</td>
<td>77.3 (5.3)</td>
<td>−3.2*</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>80.0 (7.7)</td>
<td>80.9 (8.3)</td>
<td>80.4 (7.9)</td>
<td>79.5 (7.2)</td>
<td>80.3 (7.8)</td>
<td>0.3</td>
<td></td>
</tr>
</tbody>
</table>

* Statistically significant change.

Table 5
Mean free flow speed and standard deviation on 50 km/h roads broken down by groups and the four 45-day periods: baseline, the three experiment periods and the total experiment period. The numbers inside the brackets are the (usual) sample standard deviation for the FFS observations.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
<th>Experiment 3</th>
<th>Experiments 1 + 2 + 3</th>
<th>Difference</th>
<th>BAS − EXP 1 + 2 + 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>46.9 (7.1)</td>
<td>46.0 (6.1)</td>
<td>46.5 (6.4)</td>
<td>46.3 (6.1)</td>
<td>46.3 (6.2)</td>
<td>−0.9</td>
<td></td>
</tr>
<tr>
<td>Incentive</td>
<td>47.3 (6.9)</td>
<td>47.2 (6.8)</td>
<td>47.3 (7.2)</td>
<td>47.3 (6.6)</td>
<td>47.4 (6.9)</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>47.1 (6.9)</td>
<td>46.0 (5.7)</td>
<td>46.0 (5.7)</td>
<td>46.0 (5.6)</td>
<td>46.0 (5.7)</td>
<td>−1.3*</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>47.1 (6.9)</td>
<td>47.2 (6.9)</td>
<td>46.8 (6.9)</td>
<td>46.8 (6.7)</td>
<td>46.9 (6.8)</td>
<td>−0.1*</td>
<td></td>
</tr>
</tbody>
</table>

* Statistically significant change.

where the effect of time has been removed, the estimated value of \( a \) is −3.00 km/h and −0.86 km/h for the combination and incentive groups, respectively.

Changes in standard deviation (SD) are also important as research has shown that a decrease in SD improves traffic safety (Turner, 2009). We also find a decrease on this measure in the information and the combination group; the combination group had a decrease in SD from 7.8 to 5.3 on 80 km/h roads – a remarkable decrease.

3.1.3. The 85th percentile free flow speed

Fig. 5 shows the 85th percentile free flow speed (85FFS) in the baseline and the three experiment periods for 50 km/h roads and 80 km/h roads, respectively. As regards statistical analysis, we apply the same model as the one applied in Tables 4 and 5, letting \( s_{85} \) denote the 85th percentile in the FFS distribution during period \( t \) for the \( i \)th car. As with the MFFS, there is no effect of time. Furthermore, for both 50 km/h roads and 80 km/h roads, only the information and combination groups show a statistically significant change in the 85FFS. The estimated values of \( a \) (going from baseline to experiment) for the combination and information groups, respectively are −6.9 km/h and −1.7 km/h on 80 km/h roads and −3.4 km/h and −2.8 km/h for 50 km/h roads.

3.2. The ISA phase

3.2.1. Proportion of distance driven above the speed limit plus 5 km/h (PDA)

After the experiment phase all participants were given the same driving conditions in the ISA phase: the combination of information and incentive for not exceeding the speed limit. The 13 subperiods for the ISA phases were numbered from the first one (ISA 1) to the last one (ISA 13). The Pays project was terminated with a post-baseline period of 45 days including speed data from the 91 participants who were active when the trial was terminated.

Fig. 6 shows the overall results of the ISA phase, the PDA from the ISA periods compared with a baseline period and the post-baseline period. There is logged mileage from 133 participants in one or more of the 13 ISA periods and \( N \) shows the number of participants with logged mileage in the different periods. Given that participants did not necessarily have logged data in all periods, there are e.g. only 129 participants in ISA1 and not 133. From ISA1 to ISA13 the number of participants with mileage dropped from 129 to 16.

The PDA dropped from a little above 13% in the baseline period to a little under 4% in the first ISA period; when ISA was turned off in the post-baseline period, the PDA even increased to slightly higher level than in the post-baseline period.

As in the analysis of PDA in Section 3.1.1 we apply a logit transform to the individual PDAs. Specifically, let \( r_{i} \) denote the PDA for the \( i \)th car during ISA period number \( t = 1, 2, \ldots, 13 \). The logit transform is then \( d_{it} = \ln(r_{it}/(1-r_{it})) \). The purpose of this model is to investigate if there is any statistically significant change in the PDA during the 13 ISA periods. Accordingly, we model the logit transformed PDAs as

\[
d_{it} = m + a \cdot i + u_{i} + v_{i} \cdot t + e_{it}
\]

where \( u_{i} \) and \( v_{i} \) are normally distributed random effects for the \( i \)th car. The purpose of \( v_{i} \) is to capture individual effects of time. This analysis involves 133 cars and 857 observations. Of these observations 14 have a PDA of zero, observations that we initially ignored in the analysis. The statistical analysis of the model shows that the slope term, \( a \), is statistically significant and positive. This implies

Table 6
Mean free flow speed (MFFS) and standard deviation (km/h) broken down by speed limits and ISA periods. The numbers inside the brackets are the (usual) sample standard deviation for the FFS observations.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>ISA</th>
<th>Post-baseline</th>
<th>ISA → ISA</th>
<th>ISA → POST</th>
<th>BAS → POST</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>115.0 (6.5)</td>
<td>117.0 (3.2)</td>
<td>116.9 (6.3)</td>
<td>2.1* (−3.3)</td>
<td>−0.1 (3.2)</td>
<td>2.0 (−0.2)</td>
</tr>
<tr>
<td>110</td>
<td>104.7 (6.5)</td>
<td>104.1 (2.8)</td>
<td>106.2 (6.4)</td>
<td>−0.7 (−3.8)</td>
<td>2.2 (3.7)</td>
<td>1.5 (0.1)</td>
</tr>
<tr>
<td>90</td>
<td>88.2 (6.6)</td>
<td>86.9 (2.5)</td>
<td>89.6 (6.8)</td>
<td>−1.4 (−4.1)</td>
<td>2.7 (4.3)</td>
<td>1.3 (0.2)</td>
</tr>
<tr>
<td>80</td>
<td>78.5 (6.8)</td>
<td>77.4 (2.9)</td>
<td>79.8 (7.5)</td>
<td>−1.1 (−4.0)</td>
<td>2.5 (4.6)</td>
<td>1.4 (0.7)</td>
</tr>
<tr>
<td>70</td>
<td>66.0 (6.6)</td>
<td>65.4 (2.8)</td>
<td>65.9 (6.3)</td>
<td>−0.5 (−3.8)</td>
<td>0.5 (3.5)</td>
<td>−0.1 (−0.3)</td>
</tr>
<tr>
<td>60</td>
<td>57.5 (6.4)</td>
<td>56.8 (2.8)</td>
<td>58.2 (7.0)</td>
<td>−0.7 (−3.7)</td>
<td>1.4 (4.2)</td>
<td>0.7 (0.6)</td>
</tr>
<tr>
<td>50</td>
<td>47.1 (6.9)</td>
<td>47.2 (3.2)</td>
<td>48.1 (7.4)</td>
<td>−0.2 (−3.7)</td>
<td>0.8 (4.1)</td>
<td>1.0 (0.5)</td>
</tr>
</tbody>
</table>

* Statistically change under the table.
that during the 13 ISA periods the PDA increases. Rerunning the analysis with zero PDAs replaced by near zero values, specifically $r_{ij} = 0.0001$, did not change the overall conclusion and only had a minor effect on the estimated value of the slope parameter $a$. A tendency line for the 13 ISA periods is shown in Fig. 6.

Fig. 7 shows the PDA for 80 km/h and 50 km/h roads separately. The result is different for the two speed limits. On the 80 km roads the PDA drops from 17% to below 5% from the baseline to the first ISA period and it remains statistically significantly below the baseline value; finally in the post-baseline period, the PDA on 80 km/h roads rose to nearly the same level as in the baseline period. On the 50 km/h roads the PDA is lower than on the 80 km roads in the baseline period and the difference is statistically significant, but it still drops in the first ISA periods.

For the statistical analysis of the PDA over the 13 ISA periods on 50 km and 80 km roads, we extend the model used for the statistical analysis of the overall PDA above. Let $j = 0$, 1 correspond to 50 km and 80 km roads, respectively. The logit transformed PDAs are then modelled as

$$d_{it} = m + a \cdot t + b \cdot j + c \cdot j \cdot t + u_{it} + v_{it} + e_{it}.$$  

The terms $b$ and $c$ correspond to the difference in intercept and slope for 50 km and 80 km roads. The results show that all parameters in the model are statistically significant. Hence, the way the PDA changes over time is different for 50 km/h and 80 km/h roads.

The estimates of $a$, $b$ and $c$ are 0.11, −0.22 and −0.03, respectively. Since both $b$ and $c$ are negative, the PDA for 80 km/h roads is below the PDA on 50 km/h roads at all times, and the PDA increases at a slower rate on 80 km/h roads compared to 50 km/h roads.

Fig. 8 shows PDA for participants age 18–28 and over age 28. As described earlier in this article, the project was originally meant to include only drivers under age 29; the project was later opened to include all age groups and therefore only the younger drivers reached the last ISA period, as can be seen in Fig. 8. The figure shows that in the baseline the PDA is markedly higher for the young drivers than for the more experienced drivers, but in the ISA periods the two groups have a very similar PDA. In the post-baseline period, the young drivers’ PDA fell back to nearly the baseline level, but the experienced drivers’ PDA rose from 9% in the baseline period to 12% in the post-baseline period.

For the analysis of the effect of age on the PDA we used the statistical model specified by (2). Here $j = 0$ corresponds to a person of at most age 28 and $j = 1$ corresponds to a person above age 28. All parameters except the interaction term $c$ are statistically significant. The estimated value of $b$ is negative; hence the younger drivers have in general a higher PDA than the experienced drivers. Further, the estimated value of $a$ is positive indicating an increase in PDA over time. Finally, the lack of statistical significance for $c$ demonstrates that the development of the PDA over the 13 ISA periods.
periods did not differ between the young drivers and experienced drivers.

3.2.1.1. Effect of gender on the PDA. We also considered the effect of gender on the PDA. In general men have a higher PDA than women, although this difference is not statistically significant. Specifically, we have again used the model specified by (2) assuming that \( j = 0, 1 \) corresponding to a woman and a man, respectively. Only the \( a \) parameter is statistically significant, again showing that the PDA changes over time.

3.2.2. Mean free flow speed: baseline – ISA – post-baseline

As in the experiment phase, we also calculate the MFFS for the baseline, ISA and post-baseline periods. Table 6 shows changes in the MFFS from baseline to ISA and from ISA to post-baseline divided on speed limits; roads with a speed limit of 130, 110, 90 and 80 are rural roads and 70, 60 and 50 are urban roads.

In the analysis of MFFS in Table 6 we analyse the three differences separately and separately for each speed limit. We assume the following model

\[ s_{it} = m + a_i + u_t + \epsilon_{it} \]

where \( a_i = 0 \) whenever it corresponds to an observation from the first of the two groups being compared. Notice that some cars have up to 13 MFFS observations from the ISA periods. Using the above model in the analysis of the MFFS we find that the difference BAS → ISA is statistically significant at the 5% level for roads with speed limits of 80 km/h and above. The difference ISA → POST is statistically significant for all roads except 70 km/h and 130 km/h roads. None of the BAS → POST differences are statistically significant except 50 km/h roads with a p-value of 4.73%.

In the analysis of standard deviation in Table 6 we apply the same approach as in the analysis of MFFS. The BAS → ISA and ISA → POST differences are statistically significant for all speed limits except 130 km/h.
Table 6 also shows changes in SD for the FFS measurements from baseline to ISA and from ISA to post-baseline. As expected, the SD decreased from baseline to ISA and then increased from ISA to post-baseline.

### 3.2.3. The 85 free flow speed

Fig. 9 and Table 7 show the 85FFS for the baseline period, the 13 ISA periods and the post-baseline period.

For the analysis in Fig. 9 we let $p_{i,t}$ denote the 85FFS in MFFS distribution for the 8th car during ISA period $t = 1, 2, \ldots, 13$. We apply the model

$$p_{i,t} = m + a \cdot t + u_i + \varepsilon_{i,t}$$

For all but the 130 km/h roads the $a$ term is statistically significant and positive which means that the 85FFS is increasing over the 13 ISA periods. There are numerous outliers among the 85FFS observations. In order to assess the importance of these we remove all percentiles that differ from the nominal speed limit by more than 10 km/h. Rerunning the analysis does not change the conclusions, but the assumption of homoscedastic errors seems more reasonable.

As with Table 6, in Table 7 we analyse each of the three differences separately for each speed limit. Again, let $p_{i,t}$ denote the 85FFS in MFFS distribution for the 8th car during period $t$. Here, groups refer to baseline, ISA periods or post-baseline. We apply the following model

$$p_{i,t} = m + a + u_i + \varepsilon_{i,t}$$

where $a_i$ is defined as in the analysis in Table 6. The BAS $\rightarrow$ ISA differences are all statistically significant at the 5% level except for 50 km/h roads. The ISA $\rightarrow$ POST differences are all statistically significant except for 130 km/h roads. None of the BAS $\rightarrow$ POST differences are insignificant.

### 3.3. Journey time

From society’s point of view, change in speed is the most interesting effect of ISA because it is a well-known fact that lower speed means fewer fatalities and casualties (Elvik, 2005). From the driver’s point of view, however, change in travel time may be more interesting, because busyness is often the reason why we speed. The average driving time per 100 km distance travelled was therefore calculated.

Table 8 shows the average travel time per 100 km travelled distance in minutes and broken down by periods and speed limits. The results clearly show that although speeding decreased markedly in the ISA periods, the travel time only shows small changes between the three periods. As for the 80 km/h roads, the PDA was around 16% in the baseline and post-baseline periods and around 6% in the ISA periods, but the driving time only rose by 1% from baseline to ISA and dropped by 3% from ISA to post-baseline.

### 4. Discussion

#### 4.1. Measuring speed

ISA is technology developed to help drivers maintain the speed limit. In many ISA studies, mean speed was used to show the effect of ISA, probably because mean speed measured as point speed has traditionally been used to show speed level on roads. But the problem is that mean speed is an indirect measure to describe speeding and additionally, it is difficult to define and measure an appropriate mean speed when measure data is floating car data. Indeed, one can imagine a situation where the mean speed increases, the standard deviation decreases and speeding decreases. Roughly speaking, the same problem is connected to the use of 85th percentile as a measure. Alternatively, we therefore suggested using the proportion of distance driven above the speed where the ISA system responds – we called the measure proportion of distance above the speed limit (PDA). This measure can be directly calculated from floating car data and is by definition a strict measure of the effect of ISA equipment on speeding. In this way, the study provided a platform for a much needed discussion of appropriate ways to estimate the effect of ISA and other ADAS systems on drivers’ speed behaviour. If we look at the results from PAYS across PDA, MFFS and 85FFS, it is our assessment that PDA compared to MFFS and 85FFS gives a much more precise description of the ISA effect and yields results of higher statistical significance.

#### 4.2. Project design and results

The project design ultimately had some weaknesses, partly because initially there were technical problems with the equipment, and partly because the project was stopped prematurely. Furthermore, since the participants entered the project at various points over a period of 1.5 years, one weakness is that the post-baseline was set as the same calendar period for all participants instead of at the same point of the project period for each participant. But these weaknesses are not likely to affect the main results from the project because the data set – 380 m observations – to evaluate speed behaviour – is enormous and because the effects on speed behaviour are statistically significant as the analysis shows.

In Fig. 4, PDA is shown for all speed limits, for roads with a 50 km/h speed limit and for roads with an 80 km/h speed limit. The
relative effect for 50 km/h roads and 80 km/h roads on the different groups is in line with the general results for all speed limits, but it should be noted that the PDA on 80 km/h roads is higher in the baseline period for the control and the combination groups than for the information and the incentive groups, and this difference is statistically significant. No explanation has been found for these differences. When joining the project, the participants were randomly assigned to one of the four groups, so in that respect there can be no bias.

As explained in Section 2, our hypothesis was that the speed of the information group would increase over time because the drivers get used to the female voice (Warner, 2006). We also considered it likely that the speed of the incentive group would decrease over time because of the drivers’ growing awareness of their loss of bonus when speeding. However, the results of the experiment do not support these hypotheses. This might be due to a weakness of the project design because the participants received their first bonus check after the experiment phase. Maybe it was only at this point that they became fully aware of the economic consequence of the speed limits: a reduction in the promised bonus.

The hypothesis of the study was that a combination of information and incentive would increase the ISA effect, but the field trial cannot verify this hypothesis. But why is that? The hypothesis seems likely. An explanation may be found in the composition of the participant group. As mentioned earlier in this article and described in detail in (Lahrmann in this issue), there were considerable problems recruiting test drivers for the project. It is therefore likely that most of the participants joined the project because they were motivated and wanted help to keep the speed limits. Their wish to save money on the insurance premium was of secondary importance. The next question is whether it can be generalised that an economic incentive where the starting discount is 30% on the insurance premium is enough to prevent drivers to speed? Given the recruiting problems in the project, it appears that incentive as discount on the insurance rate is not enough to ensure that ISA can be market driven.

After the experiment phase, all participants drove in the same group with a combination of information and incentive and the results are convincing. In general, PDA dropped from 13% to 4% in the first ISA period. In the 13 ISA periods there was a slide but a statistically significant increase again in the PDA, which suggests that the participants have a tendency to forget the ISA system over time. In the post-baseline period the PDA increased to 14%, which indicates that PAYS is not, as we hypothesized, an appropriate educating device. Instead, it can be characterised as an assistive system which must be in place and working to affect drivers’ speeding.

The greatest effect was on 80 km/h roads, where PDA dropped from 13% in the baseline period to a little under 4% in the first ISA period, while a minor effect was found on 50 km/h roads. These results are consistent with an attitude survey that showed a higher acceptance of the 50 km/h speed limit than the 80 km/h speed limit (Harms et al., 2008). No statistically significant gender differences were found, which is quite interesting considering that it is well known that male drivers have a higher accident rate than female (Brems and Munch, 2008). Young test drivers had a higher PDA in both the baseline and post-baseline periods, and this difference was statistically significant, but during the ISA periods there was no statistically significant difference in PDA between the two group. This result is interesting in view of the fundamental idea of the project: to prevent young drivers from speeding.

In the post-baseline period, the PDA for experienced drivers rose from 9% in the baseline period to 12% in the post-baseline period. One explanation for this surprising result is that the participants’ speed in the baseline period is influenced more by the turned-off ISA equipment than their speed in the post-baseline period. Another explanation is that in the course of the PAYS project, the participants get used to receiving speed support and when this support is removed they are less aware of the speed limits than they were in the baseline period. The latter hypothesis seems to be reliable but one could ask why there are these differences between the two age groups. The next question is: is such lack of awareness permanent or how much time will pass before their speed awareness is back at the starting level? These questions are beyond the scope of the present study.

Travel time per 100 km showed no increase even though the PDA of the participants in general decreased, thus the participants did not reach their destination later, speeding or not.

Can external factors have influenced the results? One possible factor is the general speed level on Danish roads. As shown in Table 3, the general speed level in Denmark increased on all road types except 50 km/h roads in the trial period. It is not possible to use the results in Table 3 directly, given that the participants ran in the project in different calendar periods. However, the numbers in Table 3 indicate that the results are not underestimated.
4.2.1. PAYS results compared with other ISA results

In Agerholm et al. (2008) we published some initial PAYS results based on data from 38 participants driving 158,000 km over a period of 3 months. The results presented in that article are very similar to the results in the present study though there is a tendency towards a minor effect in the present study as compared with the initial results in Agerholm et al. (2008).

When we compare the PAYS results with results from the Belgium ISA trial, the latter in many ways show the same trends as PAYS: no change in mean speed, a slight decrease in SD, a slight decrease in the 85th percentile on roads having high speed limits, and a slight decrease in the PDA were observed – mostly on high speed limit roads. Finally, as in PAYS, the effect decreased slightly over time in the Belgium ISA trial (Vlasserenoot et al., 2007).

It is slightly more difficult to compare the PAYS results with results from the Lund ISA trial. In the Lund trial, the effect was measured as change in speed for all trips run by the test drivers and passing a number of road sections. The Lund trial thus used a kind of point-based speed measure technique to calculate the effect on speed, thereby using only a small fraction of their log data in the effects analysis. In Section 2.1 of this article, we argued that point speed is not the best way to describe changes in the speed of individual drivers. Nevertheless, it is interesting to compare the PAYS results with the Lund results. The Lund trial took place only in urban areas and again the tendency is the same: the greatest decrease in mean speed and 85th percentile was observed on 70 km/harterial roads and the smallest on 50 km/h main streets. In addition, the SD decreased, the greatest decrease being on arterial roads (Várhegyi et al., 2004).

As in PAYS, the Australian ISA project TAC SafeCar calculated the effects on the free flow mean speed and free flow 85th percentile. And the effects are similar to PAYS: when ISA was active, mean speed and 85th percentile were markedly reduced. When the ISA system was disengaged in the after period, the speed increased markedly again. As in PAYS, the standard deviation was markedly reduced when the ISA system was active, while it was increased again in the after period. The TAC SafeCar project used time over speed limit + 10 km as an alternative measure for the effect. Like the PDA measure in PAYS, this measure shows that when the ISA system was active the drivers spent substantially less time driving 10 km/h or more above the speed limit as compared to the before period. As was the case for the other speed measures, however, the percentage of time spent 10 km/h or more above the speed limit increased markedly when ISA was deactivated. The result is again very similar to the PAYS results. Finally, the TAC SafeCar project looked at the mean trip time, and again as in PAYS: ISA did not markedly affect mean trip time (Regan et al., 2006).

The PAYS results show the same tendency as the last UK ISA project. In that study, the part of distance travelled over the speed limit was calculated and the effect pattern is very similar to PAYS. Still, as the PDA in the UK ISA project is the PDA over the speed limit and not the speed limit + 5 km/h, as in PAYS, the effects found in the two studies cannot be compared directly. The effect found in the UK ISA project is somewhat minor compared to PAYS, but as in PAYS the effect disappeared completely in the post-base line period. Thus, UK ISA project also failed to show did not show an educating effect.

5. Conclusion

The PAYS project stands on the shoulders of the last 10 years of ISA research around the world, studies which have all reported convincing effects of ISA among volunteers. The PAYS project was an attempt to simulate a market driven implementation of ISA in young car owners through a combination of informative ISA and incentive ISA, the incentive being a 30% discount on the insurance premium. This type of market introduction did not succeed; the 30% discount was not enough to sell ISA to young car owners and the project reached only half of the 300 participants planned. Furthermore, only half of the participants were young car owners as opposed to the original target group.

Nevertheless, the project has yielded useful knowledge. We found that informing the participants about speeding and using a bonus on the insurance premium as incentive resulted in a statistically significant decrease in speeding. Information had the greatest impact and no combination effect between the two treatments could be demonstrated. Furthermore, the effect slightly decreased over time and when the treatments stopped, the participants went back to their previous speeding behaviour.

Furthermore, PAYS has no educating effect. This means that the level of speeding returned to the previous level when PAYS was turned off.

PAYS was found to have a greater effect on 80 km/hroad than on 50 km/h roads and on young drivers as compared to more experienced drivers. Finally, the mean driving time per 100 km did not increase during the trial because of ISA.

The overall conclusion is therefore that ISA has a convincing effect on motivated drivers’ speeding, but there is also no educating effect, and finally, the offer of a 30% discount on the insurance premium does not suffice for ISA to become market driven.

Furthermore, we have argued for using distance and not time as the unit for measuring speed change in ISA and other ADAS projects and we have introduced three new units to describe the speed effect of ISA: (1) the proportion of distance above the speed limit + 5 km/h (PDA), (2) mean free flow speed (MFSS) and 85th percentile free flow speed (85FFS). The results show that PDA provides the most accurate picture of the behaviour changes in relation to the project aim to prevent speeding.

References


