SPEED REGULATION BY IN-CAR ACTIVE ACCELERATOR PEDAL

— Effects on Speed and Speed Distribution —

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The effects on speeds and speed distribution were studied in a large scale field trial with an in-car system for speed adaptation in the city of Lund, Sweden. In the trial 290 vehicles were equipped with an “active accelerator pedal” and a data logger for a period of 3–11 months. Data was logged in each test vehicle during the whole trial and was analyzed for 3 one-month periods: Before activating the system, after short time use and after long time use. The results showed significant reductions in the speed level. Speeds on stretches decreased statistically significantly ($p < 0.05$) at 60 out of 69 observed sections. The effects were largest on arterial roads, at mid-block sections, where the prevailing traffic conditions and street design allows higher speeds. The standard deviation decreased on all arterial roads, mainly due to the decrease in speed of the fastest vehicles but there was also an effect from an increase in speed of the slowest vehicles. On streets with mixed traffic no differences in speed or speed distribution could be shown. This is most likely due to the fact that speeds were already controlled by the prevailing traffic conditions and they already were so low that the system never had to interfere. Further research is needed in order to investigate possible behavioral adaptation effects when the system is active as well as inactive and how driver behavior would be influenced in a situation where a large part of the vehicle fleet is equipped with an active accelerator pedal.

Key Words: Speed adaptation, Active Accelerator Pedal (AAP), Speed, Speed variance, Traffic safety

1. INTRODUCTION

Speed adaptation via in-car devices has been studied for more than 15 years. Such systems for speed adaptation can contribute to a significant improvement of road safety[1]. Estimates of the safety effect of a fully implemented automatic speed management system in Sweden[2] and the UK[3,4] vary from a 10 percent reduction in injury accidents with an advisory system to a reduction in the range of 20–40 percent with a system that enforces current speed limits and also limits the vehicles' speed in critical conditions (slippery road, poor visibility). Previous field trials[5–7] and simulator experiments[8–10] have demonstrated the positive effects of assistance systems to support the driver via a controlled gas pedal. However, it was concluded that the long-term effects of ISA (Intelligent Speed Adaptation) on the speed level and speed variance in real traffic needed more research.

The earlier small-scale studies have demonstrated the effects of ISA on the speed level. However, if there is a possible and stable effect on speed variance too, an additional safety potential can be credited to ISA since there is a relation between the change in standard deviation of the speed and the change in accidents[11]. A review[12] of the findings of several studies showed a U-shaped relationship between vehicles' deviation from the mean speed and their accident involvement. The faster or slower a driver travelled in comparison to the mean speed, the higher was the risk for that driver to be involved in an accident.

Within the framework of the Swedish Road Administrations' 3-year evaluation program on ISA, a large scale trial was carried out among others in the city of Lund, where 290 vehicles were equipped with an “active accelerator pedal” (AAP). When the driver attempts to exceed the speed limit, a resistance in the accelerator pedal is activated. If necessary, the driver can override the system by pressing the accelerator pedal harder (kick-down function). The system included a display indicating the current speed limit, a digital map with all the speed limits within the city and a GPS system for positioning.

This paper concentrates on how mean speeds and the speed distribution of test drivers were affected by the system after a long time use. The hypotheses were:

1) The speed level will be generally lower within the test area with the AAP;
2) The speed variance will be lower with AAP.

The general reduction in speed was expected due to decrease in the highest speeds and the effect was expected to be largest where the mean speed was close to or above the speed limit. The reduction in variance was expected due to a decrease in the highest speeds but also from an increase of the lowest speeds.

2. METHOD

2.1 Test driver selection

The recruiting of the test drivers was based on a randomised sample of vehicle owners in Lund and a request to companies to allow their company cars to be included in the trial. There were a total of 290 vehicles equipped with AAP. The drivers were assigned to groups with regard to gender, age and initial attitude towards the active accelerator pedal (positive/neutral/negative) (see Table 1). The test-drivers' initial attitude was revealed by the following question in the recruiting questionnaire:

"What do you think of having the following equipment in your car? A system that gives a counter force in the accelerator when the vehicle has reached the speed limit, and the speed limit cannot be overridden except in an emergency".

☐ *"Good"* ☐ *"Not good"* ☐ *"Neither"*

A few drivers did not reveal their initial attitude to the system. It was difficult to recruit female drivers over 65 years of age (due to the fact that in this age group cars are mainly registered with the male member of the household) and young drivers (due to the fact that people below 25 years of age do not usually possess cars of recent model, suitable for being equipped with the system). Thirty-eight of the vehicles were company cars (vehicles of local companies and organisations).

2.2 The test site in Lund

The test area consisted of the entire city of Lund, approximately 27km^2 and included 30, 50 and 70km/h speed limits. The system was activated automatically when the vehicle was within the test area and could not be turned off. Outside the test area the driver could activate the system manually and set it on a desired speed limit.

2.3 Data

Data, logged in each test vehicle within the test area was (among others): date, time, position, direction, speed limit, speed and distance driven. Data was stored with a 5Hz frequency. The logged data was analysed for three periods consisting of approximately one month each; before the system was activated, directly after activation and after 3 to 11 months of driving with the system (the time each driver drove with the equipment before the last test period depended upon when the equipment was installed in their vehicle). The average time the test drivers drove with AAP was 7 months. The different observation periods are from here on referred to as: *"Without AAP", "Short time use" and "Long time use"*. For some vehicles the data is missing for one or more periods. All the data analysed in this study are from vehicles which have data for driving without AAP and at least one of the succeeding periods. Because of this the number of observations is greatest in the without period. Possible differences in speeds between the periods were tested with the t-test and sign test ($p < 0.05$).

3. ANALYSIS

3.1 Speed on stretches

For the speed analyses, 69 stretches were selected representing the street environment of Lund. The selection was made with consideration to traffic conditions and possible changes (road works, reconstruction of streets, etc. during the trial) so that the vehicles should be unaffected by changes in the street environment. The different stretches were classified with regard to street type and speed limit (see Table 2). The length of the stretches varied from about one hundred meters up to two kilometres.

Table 1 The number of test subjects according to age group, gender and initial attitude towards the active accelerator pedal

	Age group											
	18–24			25–44			45–64			65<		
	Positive	Neutral	Negative	Positive	Neutral	Negative	Positive	Neutral	Negative	Positive	Neutral	Negative
Male	4	1	2	41	7	8	61	13	12	28	3	1
Female	5	0	0	26	3	12	28	12	5	5	0	1

Table 2 The street types included in the study

Street type/ Speed limit (km/h)	Description	No. of stretches	Number of observations		
			Without AAP	Short time use	Long time use
Arterial road/70	Dual carriage way	8	5,845	4,821	3,823
Arterial road/50	Dual carriage way	10	6,101	4,476	3,711
Arterial road/50	Single carriage way	19	6,787	5,170	4,526
Main street/50	Low volume of pedestrians and cyclists	12	3,426	2,763	2,327
Main street, mixed traffic/50	High volume of pedestrians and cyclists	12	2,191	1,803	1,326
Central street/30	Frequent interactions between road user groups	8	1,521	1,333	857

3.2 Speed distribution

Spot-speeds were analysed on 3–5 spots for each street type in Table 2. The speed of the vehicles that passed that spot both without AAP and after long time use was analysed. The spots were selected so that in that section the mean speed for all vehicles without AAP was equal to the speed limit. This way, it was possible to also study changes for the vehicles that without AAP drove slower than the speed limit. If the profile of mean speeds along the studied stretch never got as high as the speed limit, the section with the highest mean speed along the stretch in question was selected.

4. RESULTS

4.1 Speeds on stretches

The results on unweighted mean speeds at mid-block for all street types are presented in Table 3. Examples of the profiles of mean speeds when driving without AAP (with a 95% confidence interval) and during short time use and long time use are presented in Figures 1 and 2. The results show clear differences in speeds between the measurement periods when driving without and with the system. In the before study, without AAP, the speed level was often higher than the actual speed limit depending on the prevailing traffic conditions. In the after study, when driving with the system, the speed level decreased to or below the actual speed limit. The largest speed reductions were recorded in those sections where the traffic environment allowed relatively high speeds (especially on arterial roads).

4.1.1 Arterial roads

On arterial roads with a dual carriage way and speed limit of 70km/h, the results show a decrease in mean speeds at mid-block sections on average by 7km/h after short time use. After long time use speeds increased somewhat, however, compared with the before period they were on average 4.9km/h lower, which is a statistically significant difference ($p < 0.05$) on all 8 observed

Table 3 Changes in mean speeds at mid-block sections on different street types

Street type/ Speed limit (km/h)	No. of stretches	Mean speed at mid-block (unweighted) for all stretches (km/h)			Change (km/h)	
		Without AAP	Short time use	Long time use	Short time use	Long time use
Arterial road/70	8	76.0	69.0	71.1	–7.0*	–4.9*
Arterial road/50	10	55.3	49.9	50.3	–5.4*	–5.0*
Arterial road/50	19	52.8	48.2	49.1	–4.7*	–3.7*
Main street/50	12	45.2	43.7	43.2	–1.5*	–2.0*
Main street, mixed traffic/50	12	38.1	37.0	37.1	–1.0	–1.0
Central street/30	8	28.7	26.3	27.0	–2.4*	–1.7

* = Statistically significant difference according to the t-test and sign test ($p < 0.05$).

stretches. An example of the profiles of mean speeds on an arterial road is shown in Figure 1.

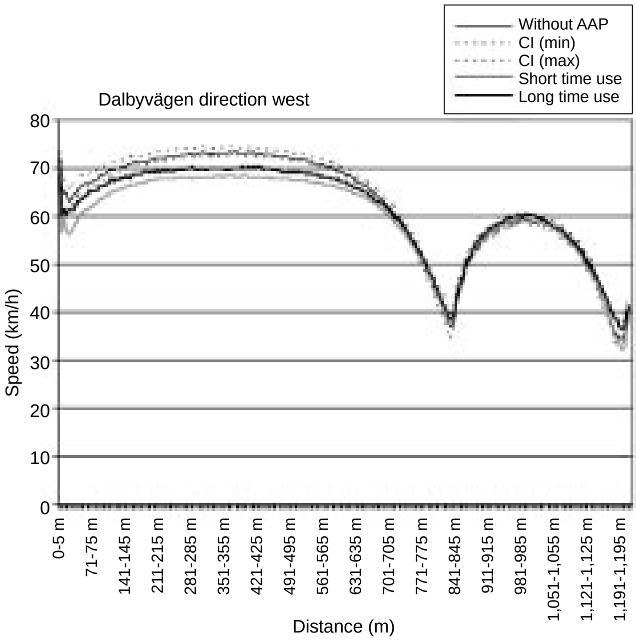

Fig. 1 Profiles of mean speeds on an arterial road with dual carriage way and speed limit of 70km/h

On arterial roads with a dual carriage way and speed limit of 50km/h, the mean speeds decreased at mid-block sections on average by 5.4km/h after short time use. After long time use compared with the before period speeds were on average 5.0km/h lower, which is a statistically significant difference ($p < 0.05$) on all 10 observed stretches.

On arterial roads with a single carriage way and speed limit of 50km/h, the mean speeds decreased at mid-block sections on average by 4.7km/h after short time use. After long time use compared with the before period speeds were on average 3.7km/h lower, which is a statistically significant difference ($p < 0.05$) on all 19 observed stretches.

4.1.2 Main streets

On main streets with a speed limit of 50km/h, the mean speeds at mid-block sections decreased on average by 1.5km/h after short time use. After long time use compared with the before period they were on average 2.0km/h lower, a statistically significant difference ($p < 0.05$) on 11 of the 12 observed stretches.

On main streets with mixed traffic and a speed limit of 50km/h, the mean speeds at mid-block sections decreased on average by 1.0km/h both after short time and long time use, which is not a statistically significant difference ($p < 0.05$).

4.1.3 Central streets

On central streets with mixed traffic and a speed limit of 30km/h, the mean speeds at mid-block sections decreased on average by 2.4km/h after short time use, which is a statistically significant difference ($p < 0.05$) on all 8 observed stretches. However, after long time use compared with the before period they were on average 1.7km/h lower, which is not a statistically significant difference ($p < 0.05$). An example of the profiles of mean speeds on central streets with mixed traffic is shown in Figure 2.

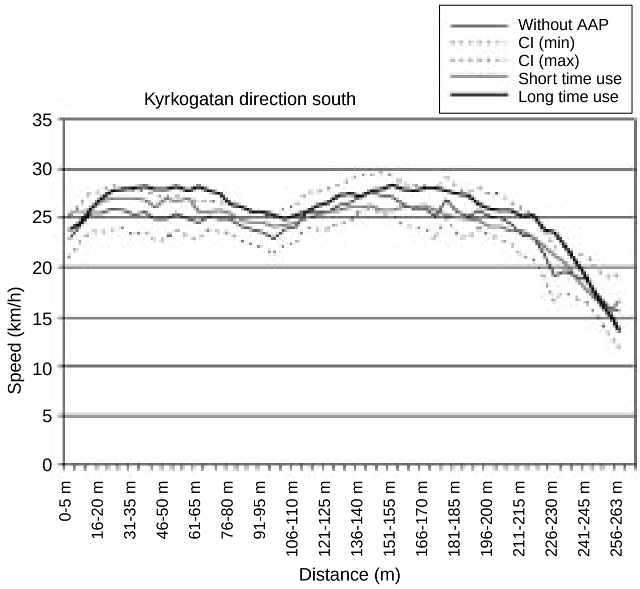

Fig. 2 Profiles of mean speeds on central streets with mixed traffic and speed limit of 30km/h

4.2 Speed distribution

Mean speeds and standard deviations at the spots selected for analysis of speed distribution (sections where the mean speed without AAP was equal to or below the speed limit) are presented in Table 4. On arterial roads (Figures 3 and 4) it is the higher speeds that are most affected. The 85th percentile speed decreased from 77 to 72km/h respectively from 55 to 51km/h in the studied sections. The speed distribution is smaller when driving with the system. This is mainly due to the decrease in the highest speeds, but there is also an effect in form of an increase of the lowest speeds. The effect on speed variance is strongest on arterial roads with 50km/h speed limit.

For main streets, as can be seen in Figure 5, the cumulative speed distribution curve moved to the left, which indicates reductions along the whole speed register, which is reflected by an unchanged speed variance (see standard deviation in Table 4). The 85th percentile decreased from 55 to 53km/h and the median speed decreased from 52 to 49km/h.

Table 4 Mean speed and standard deviation at selected spots (sections where the mean speed without AAP was equal to or below the speed limit)

Street type/ Speed limit (km/h)	Mean speed		Std. dev.	
	Without AAP	Long time use	Without AAP	Long time use
Arterial road dual carriage way/70	71.0	68.3	6.70	4.04
Arterial road dual carriage way/50	50.5	48.0	5.09	2.82
Main street/50	51.1	48.2	4.15	4.21
Main street, mixed traffic/50	39.1	38.7	5.31	4.87
Central street, mixed traffic/30	26.4	25.2	5.89	4.85

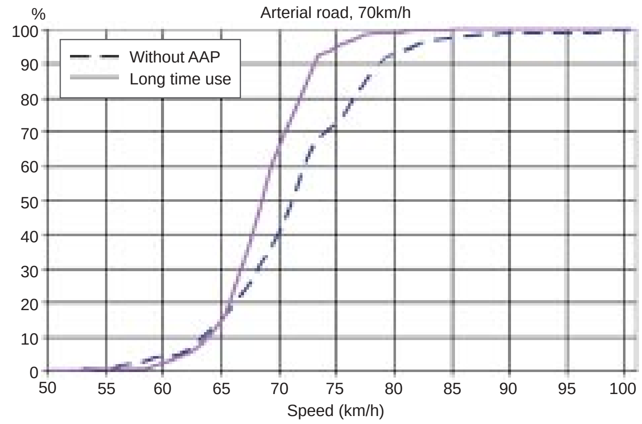

Fig. 3 Cumulative speed distribution for arterial roads with 70km/h speed limit

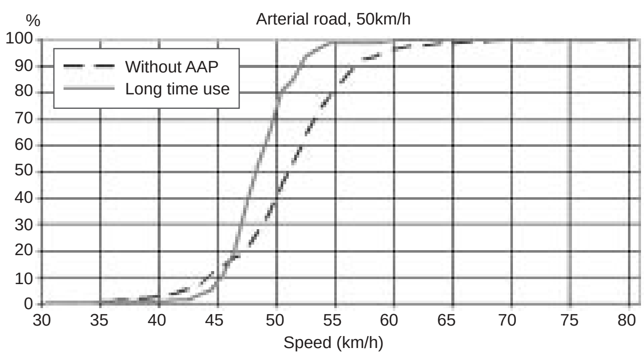

Fig. 4 Cumulative speed distribution for arterial roads with 50km/h speed limit

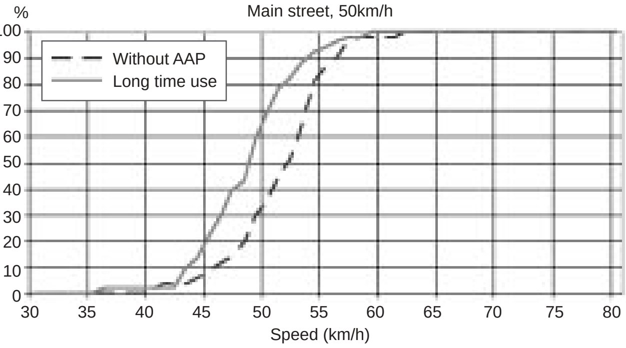

Fig. 5 Cumulative speed distribution for main streets with 50km/h speed limit

For main streets with mixed traffic the change in the speed level is marginal. It is often the prevailing traffic conditions and the street environment that controls the speed. This is particularly clear for streets with the speed limit of 50km/h, where the 85th percentile is well below the speed limit and the highest speed is 49.7km/h. As can be seen in Figure 6, the speed distribution without AAP does not differ from the distribution with AAP.

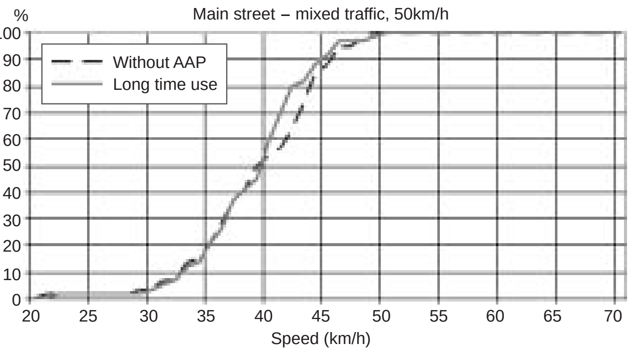

Fig. 6 Cumulative speed distribution for main streets – mixed traffic with 50km/h speed limit

For central streets with the speed limit of 30km/h, there is a change in mean speed although it is low: 1–2km/h (see Figure 7). For these streets, as for the main streets with mixed traffic, the speed is adapted more to the prevailing traffic conditions than to the actual speed limit. On these central streets, in the same way as for main streets above, the cumulative speed distribution curve moved to the left, which indicates reductions along the large part of the speed register, however the reduction of the highest speeds is somewhat larger, reflected by a decreased standard deviation (see Table 4).

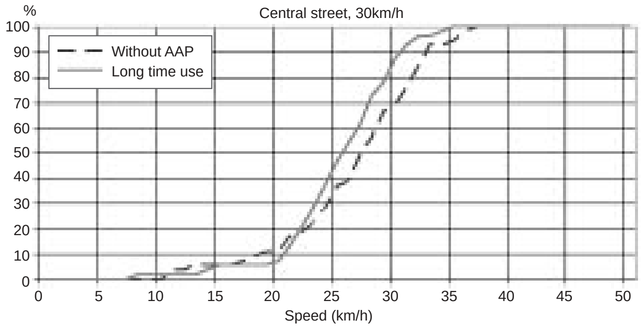

Fig. 7 Cumulative speed distribution for central streets with 30km/h speed limit

5. DISCUSSION

As expected, the results showed significant reductions in the speed level. These results are in line with earlier findings[5–10]. The new findings in the present study is that it demonstrates the long-term effects, after the test drivers' coming over the novelty period of acquaintance with the system and their adaptation to driving with a new driver assistance system.

Speeds on stretches decreased statistically significantly ($p < 0.05$) at 60 out of 69 sections after long time use of AAP. The effects are largest on arterial roads, where speeds without AAP had been above the speed limit. The reductions are most apparent at road sections where the speeds in the before situation were highest, but even at road sections with lower speeds in the before situation the AAP function had an effect. The speed reductions are largest at the mid-block sections where the traffic is not influenced by traffic lights or other hindrances. At intersections, where it is natural to slow down, the differences are not significant between the before period and when driving with the AAP system.

The effects on speed distribution are largest where the prevailing traffic conditions and street design allow higher speeds and more individual choice of speed. On arterial roads, which often are designed for higher speeds than the speed limit, the traffic volumes are, except for a short morning peak, so low that traffic can be regarded as free flowing. It is on these roads that the speed reducing effect from the AAP is the highest, but it is also here that the system's effect on speed variance is the largest. The standard deviation decreased on all arterial roads, this is mainly due to the decrease in speed of the fastest vehicles but there is also an effect from an increase in speed of the slowest vehicles. The increase in speed could be because the slower drivers are encouraged to speed up by the AAP. Another possible explanation is that the drivers use the AAP as a comfort system or a cruise control, that is, they accelerate up to the speed limit and then let the AAP control the speed. On these roads, the system will not only help the driver to keep within the speed limit, it will also encourage the slower drivers to increase their speed to the speed limit.

On streets with mixed traffic no difference in speed or speed distribution could be shown. This is most likely due to the fact that speeds were already controlled by the prevailing traffic conditions and the street design and the speeds already were so low that the AAP never had to interfere. This is supported by a study[13] on the effects of changing the speed limit from 50 to 30km/h on this type of streets where no effects at all were found since speeds before the change of the limit already were at the 30km/h level.

The reductions in mean speeds indicate a large traffic safety potential according to Nilsson's[14] model (see Table 5). On arterial roads the estimated effect on police

Table 5 The expected decrease in injury and fatal accidents after the introduction of AAP according to Nilsson 's model

Street type / Speed limit (km/h)	Mean speed at mid-block (unweighted) for all stretches (km/h)		Expected decrease in the number of injury accidents (%)	Expected decrease in the number of fatal accidents (%)
	V_1 (Without AAP)	V_2 (Long time use)	$(1-(V_2/V_1)^3)*100$	$(1-(V_2/V_1)^4)*100$
Arterial road/70	76.0	71.1	18%	23%
Arterial road/50	55.3	50.3	25%	32%
Arterial road/50	52.8	49.1	20%	25%
Main street/50	45.2	43.2	13%	17%
Main street, mixed traffic/50	38.1	37.1	8%	10%
Central street/50	28.7	27.0	17%	22%

reported injury accidents is a decrease by 18–25%, on main streets by 7–20% and on central streets 17%. We could also show reductions in speed variance and, given the relationship between speed variance and accidents established in earlier studies[11,12], this means an additional traffic safety potential.

These results are in line with earlier findings[2–4,15] where the estimated safety effect varies from a 10–20% reduction in injury accidents and up to a 30–40% reduction in fatal accidents with a system that prevents the driver from exceeding the speed limit.

6. CONCLUSIONS

The positive effects of the active accelerator pedal on the speed level and speed distribution could be confirmed and it could also be confirmed that the effect sustained after long time use of the system. The effects were largest on arterial roads where the vast majority of injury accidents occur. In this sense the AAP studied here demonstrated its great traffic safety potential.

Further research is needed in order to investigate how driver behaviour would be influenced in a new situation where a large part of the vehicle fleet is equipped with AAP and possible behavioural adaptation effects when the system is active as well as inactive.

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