In-field evaluation of the effects of Continuous Driver Support on driver behaviour

ANDRÁS VÁRHELYI*, ANNA PERSSON*, CLEMENS KAUFMANN**

* Department of Technology and Society, Lund University, Box 118, 221 00 Lund, Sweden, Phone: +46 46 222 91 29 e-mail: andras.varhelyi@tft.lth.se / anna.persson@tft.lth.se

** FACTUM OHG, Danhausergasse 6/4, 1040 Vienna, Austria, Phone: +43 1 504 15 46 e-mail: clemens.kaufmann@factum.at

Keywords: Continuous Driver Support, field tests, effects, driver behaviour, user opinions.

Abstract

User-related effects of a Driver Assistance System for Continuous Support on driver behaviour, were evaluated in a field test carried out in 2013. Twenty four drivers took part in test drives with a within-subject design along a 53 km test route containing motorway and rural-road sections. Driving data was logged and the test drivers were observed by means of an in-car observation method (Wiener Fahrprobe), i.e., by two observers in the car along with the driver. Questionnaires were used to assess the drivers' comprehension of and experiences with the system, experienced usefulness of and satisfaction with the system, as well as willingness to have and pay for the system. The results showed that there was no difference in general speed behaviour while driving with the system compared to driving without. The Curve Speed Warnings gave the expected effect. There were less dangerous lane changes with the system in active mode, but there were slightly more late adaptations of speed before intersections and obstacles. The test drivers were of the opinion that the system was useful, and that it would enhance safety especially in overtaking situations on motorways. The blind-spot warning was found especially useful in the overtaking process. The drivers appreciated the fact that the system did not give information all the time. The system was perceived as useful, while satisfactoriness was not statistically significantly different from zero. The findings provide important information that can be used by the system developer to improve system performance.

Keywords: Continuous Driver Support, field tests, effects, driver behaviour, user opinions.

1. Introduction

Advanced Driver Assistance Systems (ADAS) offer the possibility of helping the driver to avoid risky situations, e.g. inappropriately high speed, collision with an object ahead or with a vehicle in the adjacent lane, and the like. Previous studies evaluated the user-related effects of individual functions of ADAS, such as speed support (see e.g. Persson et el. 1993; Várhelyi & Mäkinen 2001; Hjälmdahl & Várhelyi 2004b; Peltola et al. 2004; Várhelyi et al. 2004; Jamson et al. 2006; Warner 2006, Regan et al. 2006; Vlassenroot et al. 2007; Adell et al. 2008; Adell et al. 2010; Lahrmann et al. 2011), warning of inappropriate distance to the car ahead (see e.g. Regan et al., 2006; Adell et al. 2010;), and blind-spot warning (see e.g. Chun et al. 2013).

In the EU-financed project interactIVe, a Continuous Support (CS) system was developed integrating such functions and this paper presents the user-related assessment of this system. When the system detected a hazard, it issued a warning to the driver. The level of warning depended on the degree of the hazard (at a higher degree of hazard sounds and active feedbacks were also activated in the safety belt). The system provided the following warnings to the driver:

- When the actual speed was above the speed limit, the display showed the speed limit icon.
- When approaching a curve at a too-high speed, the display showed a yellow curve icon as a pre-warning; the display showed a red curve icon, an alarm sound was activated and the safety belt was tensioned as an imminent warning.
- In a situation with the risk of a forward collision, the display showed a yellow obstacle icon as a pre-warning; the display showed a red obstacle icon, an alarm sound was activated and the safety belt was tensioned as an imminent warning.
- In a situation with a vehicle in the blind spot, the display showed a yellow blind-spot obstacle icon as a pre-warning; the display showed a red blind-spot obstacle icon as an imminent warning.

The aim of the user-related assessment was to evaluate the effects on driver behaviour, driver reactions to and acceptance of the Continuous Support system.

Based on findings of earlier studies, mentioned above, the following hypotheses (formulated as null-hypotheses) were tested:

1. Driving speed does not differ while driving with the system compared to driving without the system.
2. There is no difference in the number of alarm situations while driving with the system compared to driving without the system.
3. There is no difference in alarm length while driving with the system compared to driving without the system.
4. There is no other change in behaviour while driving with the system (lane keeping, lane change, interaction with other road users, etc.).

Besides these hypotheses, several issues concerning driver experiences, perceptions, opinions and acceptance were investigated, e.g. the driver's emotional state and mental workload while driving with the system, the drivers' experienced Usefulness and Satisfactoriness of the system and their willingness to use and pay for the system.

2. Method

Twenty four drivers took part in the test drives (13 males and 11 females). They were employees at Centro Ricerche FIAT (CRF) and not involved in the interactIVe project. They had been driving cars for between 9 and 37 years, with an average of 21.2 years (SD=7.2). They drove between 3000 and 35000 km a year, with an average of 17000 km a year (SD=8251). Seven of them usually drove an economy car (up to 15000 €), fifteen stated they drove a middle-class car (15000 – 25000 €) and one drove a luxury car (over 25000 €).

The test route was 53 km long, containing motorway and rural-road sections. It took approximately 40 to 45 minutes to complete. Every test driver was given time to become familiar with the situation and the car before the real observations started. Therefore, there was an additional 10 to 15 minute drive before the test drive.

The test drivers drove twice along the test route, and served as their own controls. The order of driving was arranged so that every other subject drove first with the system switched off and then with the system switched on. For each following driver the order of driving was reversed. By doing this, the effects of biasing variables, such as getting used to the test route, or to the observers and the test situation, could not be eliminated, but could be spread evenly across the situations.

Before the test drives, the drivers were informed that the trial was about the system and not about them as drivers, and that all data collected would be anonymous. They were instructed to drive as normally as possible, and ask any questions or express any doubts they might have during the test. Before using the system, the drivers were given a brief explanation of the system.

The test vehicle (a Lancia Delta passenger car with automatic transmission) was equipped with logging facilities, and data on vehicle status, system activities and driver-generated events was logged. The logged data was analysed in order to study the interaction between the test driver and the CS system, focusing both on general driver behaviour and behaviour after an alarm. The following variables were explored to study the impact of the system on driver behaviour:

- Number of generated warnings for speed, forward collision and side collision risk,
- Alarm length (time spent in alarm phase).

The test drivers were observed by means of an in-car observation method (Wiener Fahrprobe), originally developed by Risser (1985) and designed to observe learner drivers. The method also proved to be useful for studying driver behaviour in real traffic. The observations were carried out by two observers present in the car with the driver, with one of the observers (called the coding observer) studying standardised variables such as speed behaviour, yielding behaviour, lane changes, indicating behaviour etc. The other observer carried out ‘‘free observations’’ such as conflicts, communication with other road users and special events that are hard to predict, let alone standardise. The method was validated by Risser (1985) when he showed that there was a correlation between observed risky behaviour and accidents. Another validation work was done by Hjälmdahl and Várhelyi (2004a), who showed that drivers’ speed levels with observers in the car did not differ from their speed levels when they drove their own cars (without observers). They also demonstrated that it was possible to train observers to perform the observations objectively and reliably. In the present study, an instrumented vehicle was used in addition to the observers to increase the quality of registered standardised variables, e.g. speed, and to make it possible to measure and register time gaps to the vehicle in front. The variables of the standardised observations (driver performance, use of turning indicators, speed adaptation, lane change and lane use, overtaking, giving way, red running, and interaction with vulnerable road users were analysed both individually and on the aggregated level. The Wilcoxon (paired) sign rank test was used to analyse differences between driver behaviour with the system on and with the system off. The variables registered by free observations were analysed through categorisation. The registered events were categorised with the system and without the system. The video recording and the logged data were used to examine any unclear events during the analysis. Within each category the nature of the events was compared with the system on and with the system off.

Questionnaires were used to assess the drivers' comprehension of and experiences with the system. After the first ride the drivers answered a short workload questionnaire. After the second ride a more comprehensive questionnaire was filled out. This questionnaire covered the following issues:

- Experienced effects of the system

  To assess what effects the drivers' experienced while using the system, they were asked to state their thoughts on how different aspects of driving changed while using the system. They were also asked to compare their experiences of using the system to their experience of driving without the system, on a continuous scale from "decreased greatly" to "increased greatly" where "neither" represented the middle point.

- Subjective workload

  Subjective measurements of the test drivers' workload were recorded with the help of the Raw Task Load indeX (RTLX) method proposed by Byers et al. (1989). According to this method, the subjects rate six different workload aspects, namely *mental demand, physical demand, time pressure, performance*, *effort and frustration level*. Continuous scales ranging from "very low" (0) to "very high" (100) were used. The difference in workload between driving with the system on compared to driving with the system off was calculated for each test driver as Workload (on) – Workload (off).

- Usefulness and satisfaction

  Acceptance of the system was measured by the usefulness and satisfaction method proposed by van der Laan et al (1997). According to the method, the subjects assess nine components related to usefulness and satisfaction: "good – bad", "pleasant – unpleasant", "effective – superfluous", "nice – annoying", "likable – irritating", "useful – useless", "assisting – worthless", "desirable – undesirable", "raising alertness – sleep inducing". The test drivers were asked to rate the different components on a continuous scale.

- Willingness to have and pay

  Questions were asked in order to get information on the willingness to pay for the system.

- Furthermore, after each test ride, the observers conducted a short interview with the test drivers, asking them about their general feelings about using the system, possible problems during the test drives and comments regarding the system and how it could be improved. Also, comments of the test drivers regarding the system, while driving on the test route, were noted by the observers.

To test the statistical significance of differences from the answer "unchanged", the one-sample t-test was employed. The open questions were analysed through categorisation.

3. Results

Free driving speeds

Free driving speeds, when the test drivers could choose their speed without disturbance of surrounding traffic on the different types of roads, were analysed for road sections with speed limits of 50, 90 and 130 km/h. Free driving speed profiles were plotted individually for each of these sections, after which profiles of mean free driving speeds were created for both driving without the system and driving with the system. No statistically significant difference in mean free driving speeds could be shown for any of the analysed sections, as the profile of mean driving speeds with the system was within the 95% confidence interval of the means of driving without the system. This finding indicates that the test drivers did not alter their general speed behaviour while driving with the system compared to driving without the system.

Speed warnings

All warnings the driver received along the whole test route while driving with the system on (and would have received while driving without the system, but with the HMI disabled) were registered. The codes of the various speed warnings and their content are presented in Table 1.

Table 1. Coding and content of speed warnings.

Code	Warning level	Action
2	Speed limit warning	display of speed limit icon
4	Curve speed pre-warning (yellow level)	display of yellow curve icon
6	Curve speed imminent (red level)	display of red curve icon tensioning of safety belt alarm sound

Speed limit warnings

The number of warnings while driving with the system was higher for 12 test drivers and lower for 9 test drivers than while driving without the system. The mean number of warnings per driver (26) was unchanged; hence it can be concluded that there was no change in the number of speed warnings. The length of the speed warnings while driving with the system was shorter for 12 test drivers, and longer for 9 test drivers, than while driving without the system. The mean length of speed warnings without the system was 12.29 sec and with the system 11.65 sec, a decrease of 0.64 sec, a statistically non-significant difference (p=0.5) according to t-test.

Curve speed warnings

Curve speed warnings were concentrated to one specific site, i.e. just before entering a roundabout. Otherwise, only 5 individual speed warnings (code 6) were received at four other places along the whole route for all rides. The speed profiles for all passages with curve speed warnings (code 6) were plotted individually from 10 seconds before to 10 seconds after a warning was issued. The profiles of speeds in Figure 1 represent the mean of 10 individual curves while driving without the system (HMI disabled) and 14 curves with the system. As Figure 1 illustrates, when the warning is issued, the driver has already started to decrease speed, but, while driving with the system, the mean of lowest speeds is statistically significantly lower throughout the roundabout (outside the 95% confidence interval of the means of driving without the system), than while driving without the system.

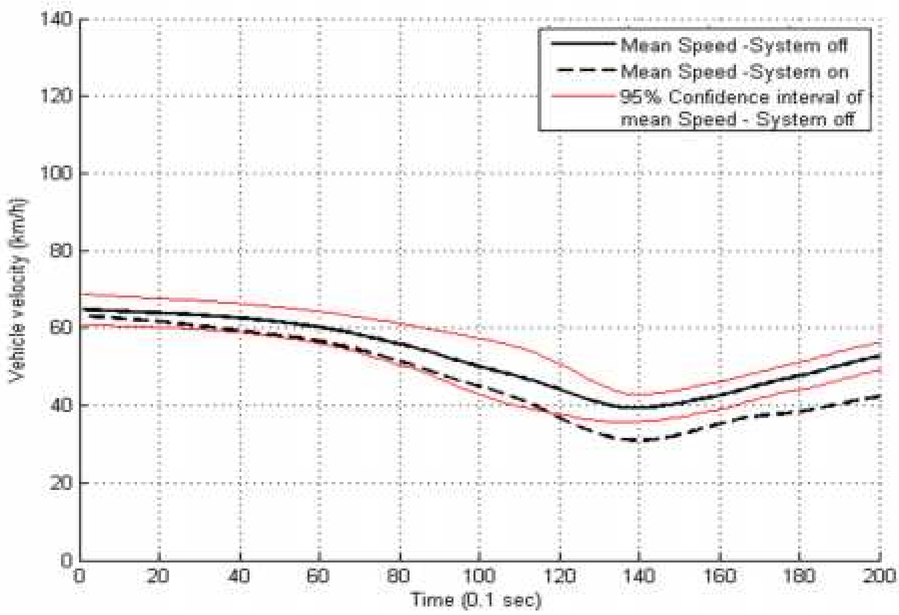

Figure 1. Profiles of mean speeds while driving without and with the system and a curve warning (code 6) is issued (warning issued at 100).

Forward collision warnings

The codes of the forward collision warnings and their content are presented in Table 2.

Table 2. Coding and content of forward collision warnings.

Code	Warning level	Action
5	Forward collision pre-warning (yellow level)	display of yellow obstacle icon
7	Forward collision imminent (red level)	display of red obstacle icon tensioning of safety belt alarm sound

The number of pre-warnings (code 5) during driving with the system was higher for 15 test drivers and lower for 6 test drivers than during driving without the system, a statistically non-significant difference according to the sign test (p=0.05). The mean number of warnings (code 5) per driver increased from 8.95 to 10.19 by 1.24.

The number of imminent forward collision warnings (code 7) during driving with the system was higher for 11 test drivers, lower for 7 test drivers and unchanged for 3 test drivers, a statistically non-significant difference according to the sign test (p=0.05). The mean number of warnings per driver increased from 2.95 to 3.57.

The conclusion is that there is some tendency for an increased number of forward collision warnings while driving with the system, but no statistically significant difference can be shown (p=0.05). This tendency might be due to test drivers challenging the performance of the system.

The length of the forward collision pre-warnings (code 5) during driving with the system was shorter for 8 test drivers and longer for 13 test drivers than during driving without the system.

The mean length of warnings without the system was 16.19 sec and with the system 16.71 sec, a slight increase of 0.53 sec, but a statistically non-significant difference (p=0.5) according to t-test.

The length of imminent forward collision warnings (code 7) during driving with the system was shorter for 9 test drivers and longer for 12 test drivers than during driving without the system. The mean length of warnings without the system was 2.19 sec and with the system 2.67 sec, a slight increase of 0.48 sec, but a statistically non-significant difference (p=0.5) according to t-test.

Side collision warnings

The codes of the side collision warnings and their content are presented in Table 3.

Table 3. Coding and content of side collision warnings.

Code	Warning level	Action
1	Side obstacle	display of yellow blind-spot obstacle icon
3	Side obstacle + stalk	display of yellow blind-spot obstacle icon
4	Side obstacle + lane drift	display of red blind-spot obstacle icon

Left side warnings

The number of side obstacle warnings (code 1) from the left during driving with the system was higher for 8 test drivers and lower for 13 test drivers than during driving without the system, a statistically non-significant difference according to the sign test (p=0.05). The mean number of warnings (code 1) per driver decreased by 1.96, from 30.10 to 28.14.

The number of side obstacle warnings of code 3 during driving with the system was higher for 11 test drivers, lower for 7 test drivers and unchanged for 3 test drivers, a statistically non-significant difference according to the sign test (p=0.05). The mean number of warnings per driver increased from 1.81 to 2.10.

The number of side obstacle warnings of code 4 during driving with the system was higher for 8 test drivers and lower for 13 test drivers, a statistically non-significant difference according to the sign test (p=0.05). The mean number of warnings per driver decreased from 5.10 to 3.48. The conclusion is that there is no difference in the number of side collision warnings from the left while driving without and with the system.

The length of the side collision warnings from the left (code 1) during driving with the system was shorter for 10 test drivers and longer for 11 test drivers than during driving without the system. The mean length of warnings without the system was 126.6 sec and with the system 123.5 sec, a slight decrease of 3.1 sec, but a statistically non-significant difference (p=0.5) according to t-test.

The length of code 3 side collision warnings from the left during driving with the system was shorter for 9 test drivers and longer for 11 test drivers (one unchanged) than during driving without the system. The mean length of warnings without the system was 2.16 sec and with the system 3.76 sec, an increase of 1.6 sec, but a statistically non-significant difference (p=0.5) according to t-test.

The length of code 4 side collision warnings from the left, during driving with the system was shorter for 14 test drivers and longer for 7 test drivers than during driving without the system. The mean length of warnings without the system was 7.78 sec and with the system 6.88 sec, a slight decrease of 0.9 sec, but a statistically non-significant difference (p=0.5) according to t-test.

Right side warnings

The number of side obstacle warnings (code 1) from the right during driving with the system was higher for 11 test drivers and lower for 9 test drivers (one unchanged) than during driving without the system, a statistically non-significant difference according to the sign test (p=0.05). The mean number of warnings (code 1) per driver decreased by 1.43, from 26.14 to 24.71.

The number of side obstacle warnings of code 3 during driving with the system was higher for 4 test drivers, lower for 12 test drivers and unchanged for 5 test drivers, a statistically non-significant difference according to the sign test (p=0.05). The mean number of warnings per driver decreased from 3.43 to 2.67.

The number of side obstacle warnings of code 4 during driving with the system was higher for 8 test drivers and lower for 12 test drivers (one unchanged), a statistically non-significant difference according to the sign test (p=0.05). The mean number of warnings per driver decreased from 11.9 to 11.33. The conclusion is that there is no difference in the number of side collision warnings from the right while driving without and with the system.

The length of the side collision warnings from the right (code 1) during driving with the system was shorter for 10 test drivers and longer for 10 test drivers (one unchanged) than during driving without the system. The mean length of warnings without the system was 51.45 sec and with the system 48.88 sec, a slight decrease of 2.57 sec, but a statistically non-significant difference (p=0.5) according to t-test.

The length of code 3 side collision warnings from the right during driving with the system was shorter for 13 test drivers and longer for 6 test drivers (2 unchanged) than during driving without the system. The mean length of warnings without the system was 2.58 sec and with the system 1.91 sec, a decrease of 0.67 sec, but a statistically non-significant difference (p=0.5) according to t-test.

The length of code 4 side collision warnings from the right during driving with the system was shorter for 12 test drivers and longer for 9 test drivers than during driving without the system. The mean length of warnings without the system was 11.54 sec and with the system 10.19 sec, a decrease of 1.35 sec, but a statistically non-significant difference (p=0.5) according to t-test.

Observed driver behaviour

Several conflict situations (test driver on a collision course with another road user followed by an evasive action by one of them) were observed on both rides with and without the system activated. While driving with the system activated, 6 conflicts were caused by the test drivers, and while driving without the system activated, 2 conflicts were caused by the test drivers. In most of the cases the evasive action to solve the conflict was taken by the test driver. Only in one conflict situation was the evasive action taken by another road user, while in another situation both the test driver and the other road user took the evasive action.

Driving too fast according to the situation was observed to be statistically significant less often with the system activated. Also, driving too far to the right and dangerous lane changes were observed to be statistically significant less often with the system activated. The test drivers chose a wrong lane while driving through an intersection or roundabout less frequently with the system activated.

On the negative side, it can be noted that slightly more late adaptations of speed before intersections and obstacles were observed while driving with the system. Also, statistically significantly more errors regarding dangerous distance to the side were observed with the system activated. It also was observed that the test drivers turned at a speed that was too high, but only while driving with the system activated.

No major differences were found regarding speed choice while driving with or without the system. The test drivers drove over the speed limit (on both rural-road and motorway sections) on both driving occasions. Moreover, the test drivers drove too fast through curves and approached a roundabout or drove through it too fast, in addition to accelerating before leaving the roundabout to the same extent on both driving trips. Sticking to own priority was observed in equal numbers on both occasions, with and without the system. No statistically significant differences between the two drives could be shown regarding dangerous distance to the vehicle in front, illegal or aborted overtaking manoeuvres, correct indicating behaviour, drifting or crossing the solid line, crossing a stop line at intersections or roundabouts, driving against yellow at a traffic light, yield behaviour and ignoring pedestrians/cyclists. Regarding interaction behaviour with other road users, hardly any differences could be observed. Situations on both drives were noted where the test drivers either made errors in the interaction processes or showed respectful behaviour towards other road users. On both occasions, situations were observed in which the test drivers did not choose the correct speed, drove without foresight or too close to other road users, showed unclear behaviour to other road users or did not behave correctly in overtaking manoeuvres. The test drivers also showed respectful behaviour towards other road users on both drives by giving way in different situations or adapting their speed and lateral position well.

Questionnaire answers

To assess the drivers' perceptions of the system, they were asked to state how they thought different aspects of driving changed while using the system. The drivers were asked to compare their experience of using the system to driving without the system on a continuous scale from "decreased greatly" to "increased greatly" where "neither" represented the middle point.

According to the test drivers, safety in traffic increased with the system, see Figure 2. The risk of getting a speeding ticket, travel time and fuel consumption were not believed to be affected by the use of the system. The system did not affect the emotional state of the drivers fundamentally, but the drivers experienced an increase in irritation ($p<0.05$). The test drivers thought that stress, enjoyment while driving, the feeling of being in the way of others, the attention to traffic, the image and the comfort were not affected by the system.

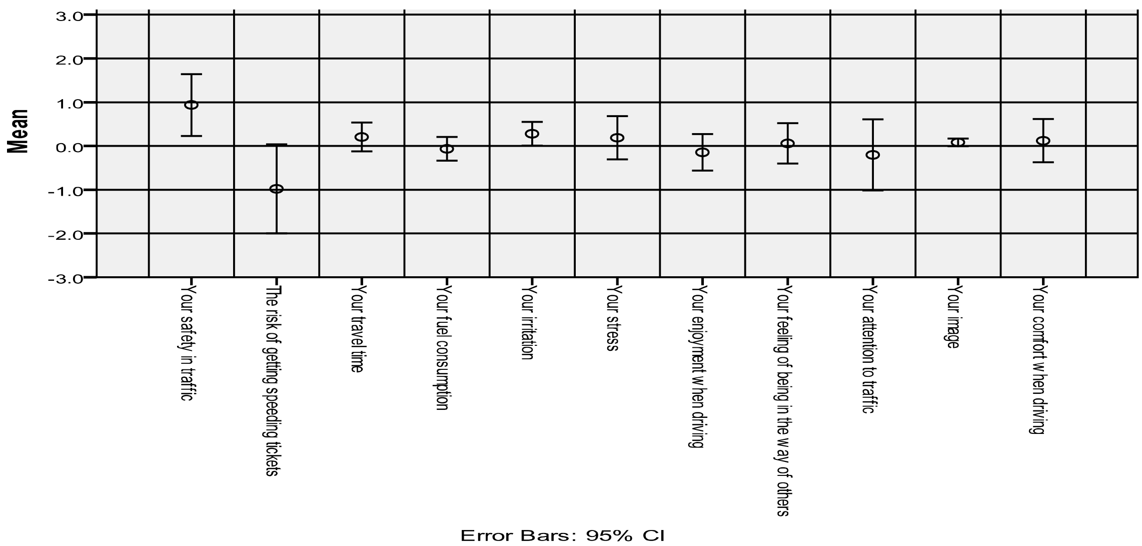

Figure 2. Mean values and 95% confidence intervals of answers to the question: What differences did you notice while using this system compared to driving without the system? (lower values = Decreases greatly; higher values = Increases greatly).

Usefulness and satisfaction

The system was perceived as useful ("useful", "good", "effective", "assisting" and "raising alertness" – all items $p<0.05$), while "desirable" was the only item on the satisfactory scale which was assessed significantly higher ($p<0.05$), see Figure 3.

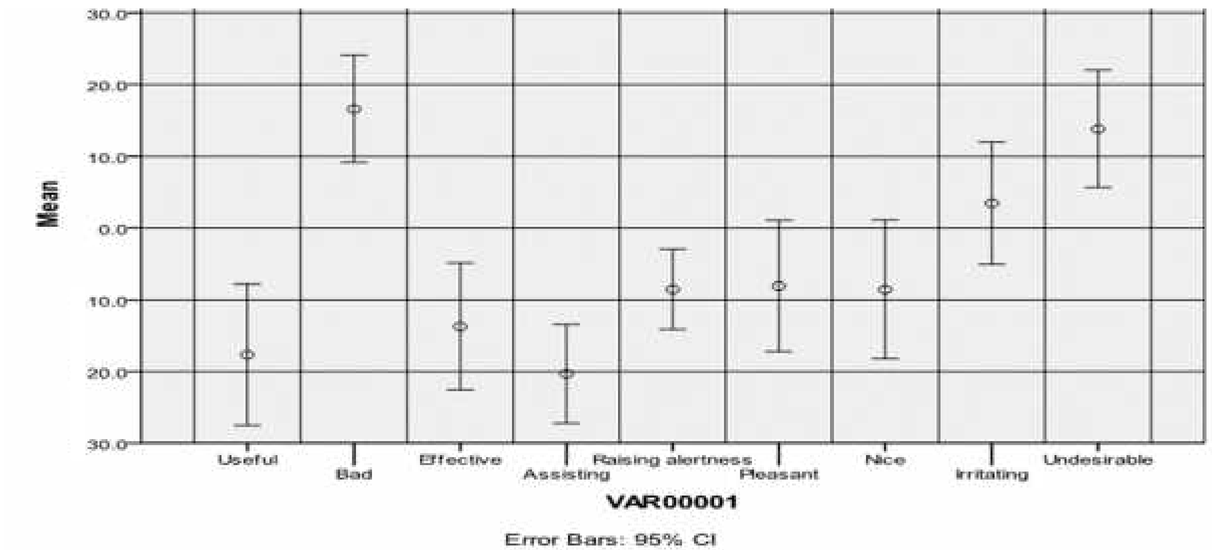

Figure 3. The drivers' rating of the items included in the assessment of "usefulness" of and "satisfaction" with the system.

Subjective workload

The subjective workload in general was not affected by the use of the system. The drivers assessed only one item, i.e. their performance to decrease statistically significantly ($p<0.05$) while driving with the system, see Table 4.

Table 4. The mean, minimum and maximum numbers of subjective workload and results from the Wilcoxon (paired) signed rank test between driving with and without the system.

	Without system activated			With system activated			Sign. of difference
	Mean	Min	Max	Mean	Min	Max	
Mental activity	-1.5	-4.9	2.9	-1.2	-4.7	3.2	0.268
Physical activity	-2.8	-4.8	0.7	-2.5	-4.8	0.8	0.112
Time pressure	-2.5	-4.8	1.1	-1.5	-4.9	3.8	0.072
Own performance	1.6	-0.7	5	0.9	-1.4	4.9	**0.001**
Effort	-2.0	-4.9	1.7	-1.7	-4.9	3.1	0.391
Frustration	-2.1	-4.9	2.9	-2.5	-4.8	1.4	0.410

Test drivers’ comments

Table 5 shows an overview of the comments of the test drivers regarding the system in general, as well as for each specific function.

Table 5. Overview of the test drivers’ comments in general and regarding each specific function.

	Advantage	**Disadvantage**	**Proposed improvements**
General	• system was helpful • did not give information all the time on what the driver should do • no problems using the system and easy to use the different functions • enhanced safety especially in overtaking situations on motorways	• warnings came too late, possible dangerous situations were recognised before the system showed it • in some emergency situations no visible information was given or it wasshown only for a short time • some test drivers did not trust the system or "instinctively" doubted the information • in the long run, the system might reduce the attention	• the visual display for the warning should be put as high as possible so that it will not be covered by the steering wheel while driving through a curve • „training“ with the warnings would be useful
Speed warning	• draws attention to the current speed limit • helps to avoid fines • especially useful when the speed limit changes	• non-accurate speed limit warnings	
Blind spot warning	• important information about vehicles coming from behind • especially useful in an overtaking process	• one might not use the mirrors anymore as the information on the dashboard is very reassuring	• additional haptic warning especially for the blind-spot warning
Forward collision warning	• helpful to keep a safe distance especially in overtaking processes	• false alarms • annoyed by the wrong seat belt warnings • seat belt warning not correlated with the real hazardousness of the situation • too short visual information • distracted by the warnings (aborted overtaking manoeuvre)	• warning signal could be “stronger” in order to get the attention of the driver in situations when he/she might be distracted
Curve warning		• false alarms • annoyed by the wrong seat belt warnings • seat belt warning not correlated with the real hazardousness of the situation	

Willingness to pay and use

The test drivers were asked to indicate the price they would be willing to pay for the system. Eleven (almost half) were willing to pay up to 250 Euros to implement the system in their cars. Eight (about one third) were willing to pay between 250 and 500 Euros and two were willing to pay between 500 and 750 Euros for the system. Two drivers had no opinion regarding this question and one did not answer the question.

The drivers were also asked to estimate, in terms of their driving time, how much they would use the system on different types of roads. More than two thirds thought that they would use the system up to 60 % of the time while driving on motorways, while 14 stated that they would use it up to 60% of the time while driving on rural roads. On urban roads, “only” nine test drivers (about one-third) stated that they would use the system up to 60% or more while driving. On the other hand, six test drivers (about one-quarter) stated that they would use the system on motorways, and seven on rural roads, up to 40 % of their driving time, while twelve stated that they would use the system in urban areas up to 40% of their driving time, see Table 6.

Table 6. Number of answers regarding “How much of your driving time you think you would use the system?”

	0-20% of time	20-40% of time	40-60% of time	60-80% of time	80-100% of time
Driving time on motorways	3	3	1	7	10
Driving time on rural roads	4	3	3	9	5
Driving time on urban roads	9	3	3	5	4

Discussion

The hypotheses 1 – 3 concerning unchanged speeds, number of alarms and alarm lengths cannot be rejected. No major differences were found regarding speed choice (driving over the speed limit, speeds through curves and roundabouts) while driving with or without the system. There was no difference in the number or length of the speed warnings, or the number or length of the side collision warnings from left or right while driving without and with the system. Some of these findings are in contrast to the earlier findings of Adell et al. (2010), who found that while driving with a system that warned of unsafe speed or unsafe distance to the vehicle ahead, the number of alarm situations was smaller than while driving without the system. However, in Adell et al., the curve alarm length and obstacle alarm length were lower on motorway sections and unchanged on rural roads and urban roads; for a summary, see Table 7.

When it comes to hypothesis 4, about any other changes in behaviour while driving with the system, the majority of observed behaviour variables are unchanged, but there are changes in a positive direction for some behavioural variables, and in a negative direction for other variables.

No differences between the two drives could be shown regarding distance to the vehicle in front, overtaking manoeuvres, correct indicating behaviour, crossing the solid line, late or hesitant lane change before an intersection, stopping behaviour at intersections, driving against yellow at traffic lights, yield behaviour and interaction behaviour with other road users. The last finding is not in line with the findings of Persson et al. (1993), who assessed driver behaviour while driving with a speed limiter, and found a slight increase of incorrect behaviour towards other road-users at junctions. In addition, assessing the effects of a system warning of unsafe speed or unsafe distance to the vehicle ahead, Adell et al. (2010) revealed that the drivers seemed to show worse facilitating behaviour towards other road users with the system on. However, evaluating the effects of a speed support system, Hjälmdahl & Várhelyi (2004b) showed that the drivers' behaviour towards other road users improved. They showed a more correct yielding behaviour at intersections, and yielded early for pedestrians to a higher extent when driving with the system. Adell et al. (2010) also noted, in contrast to findings of the present study, that the number of times the drivers crossed the centre line increased when the system was on.

Driving too fast, given the situation, was observed less often during driving with the system activated. Due to curve speed warnings, the test drivers passed the roundabout at lower speeds while driving with the system. Driving too far to the right and dangerous lane changes were observed less often while driving with the system activated. Wrong lane choice when driving through an intersection or roundabout was less frequent while driving with the system on.

On the negative side, it can be noted that slightly more late adaptations of speed before intersections and obstacles were observed while driving with the system on. More errors regarding dangerous distance to the side were observed with the system activated. Only during driving with the system activated was it observed that the test drivers made turns at too high speeds.

Table 7. The effects on driver behaviour while driving with the system (along with findings from previous studies).

Variable	**Effect**			
	Present study	Persson et al. (1993)	Hjälmdahl & Várhelyi (2004b)	Adell et al. (2010)
Speed adaptation to the situation	+			
Speed in curve	+			
Lane choice	+			0
Lane change	+			0
Lane keeping	+			0
Number and length of speed warnings	**0**			+
Number and length of forward collision warnings	**0**			+
Number and length of side collision warnings	**0**			
General speed behaviour	**0**	+	+	0
Distance to the vehicle in front	**0**	+	+	
Overtaking manoeuvres	**0**			0
Use of turning indicator	**0**			0
Crossing the solid line	**0**			-
Stopping behaviour at intersections	**0**			
Driving against yellow	**0**			0
Yielding behaviour	**0**		+	
Interaction/communication with other road users	**0**	-	+	-
Late speed adaptation before intersections and obstacles	**-**			
Turning at high speed	**-**	-		
Dangerous distance to the side	**-**			

+ = Improvement; 0 = No major change; - = Deterioration

The system did not affect the emotional state of the drivers, but they did feel an increase in irritation. They thought that safety in traffic increased while using the system. The subjective workload was in general not affected by the use of the system; the drivers assessed only one item, i.e. their performance to decrease statistically significantly while driving with the system. The system was perceived as useful, while satisfactoriness was not statistically significantly different from zero.

Conclusions

The user and observer comments provide important information that can be used by the system developer to identify major problems (mainly false alarms) and improve system performances with updated releases of the application software.

To summarize, the system was assessed to be useful with respect to the following:

- It was felt that the system would enhance safety especially in overtaking situations on motorways.
- It was noted that the system did not provide information all the time.
- It was thought that the speed warning drew attention to the current speed limit. It will be especially useful when the speed limit changes, and consequently help in avoiding fines.
- The blind-spot warning was found especially useful in the overtaking process.

On the other hand, the following improvements are necessary:

- The test drivers were annoyed by the wrong seat belt warning, as it made them anxious. The pressure was not correlated with the real hazardousness of the situation, and it came in addition to the acoustic warning.
- Warnings came too late and possibly dangerous situations were already recognised before the system showed it.
- In emergency situations no visual information was given or it was shown only for too short a time, so the test drivers did not know the reason for the haptic or acoustic warning.

The most relevant findings on how the driver interface can be improved are as follows:

- The signal for the forward collision warning could be “stronger” in order to get the attention of the driver in situations when he/she might be distracted.
- The warning icon should be kept for a longer period after the warning is issued.
- The visual display for the forward collision warning should be put as high as possible so that it will not be covered by the steering wheel while driving through a curve.
- The test drivers would prefer an additional haptic warning for the blind-spot warning.
- Safety belt tensioning should not be used for both speed warning and forward collision warning.
- Another proposal was that some training with the warnings would be useful before using the system, at least to get to know the different warning signals in order not to be surprised when they appear the first time.

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