AN ERGONOMICS EVALUATION OF THE SAFETY IMPACT OF A NEW ON-BOARD SYSTEM: SAFEMAP

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ABSTRACT

The SafeMap project, which is part of the DEUFRAKO programme (a cooperation between France and Germany), aims at assessing the use of a dedicated digital map for road safety applications. The consortium includes car and trucks manufacturers, map providers, universities, and other research agencies. The objectives are to define the database content in regards to safety, benefits, and data provision costs, to assess the feasibility of map data provision, to optimize the data provision chain (public authorities and private companies contributions), to provide a demonstrator with this system embedded, to evaluate in-vehicle safety applications using digital maps and driver acceptability.
Based on criteria of safety effectiveness and ease of implementation/deployment, Volvo has developed the following four functions for trucks:
(A) *Speed Limit Assistant,*
(B) *Curve Speed Warning,*
(C) *Frequent Accident Spot Warning,*
(D) *Physical restrictions warning*.
The aims of the present study were to assess the impact of information/warnings on driving, and to evaluate the acceptability of the SafeMap system as implemented by Volvo on an instrumented truck.

INTRODUCTION

Advanced Driver Assistance Systems (ADASs) have been developed to meet two major objectives; "to improve driver comfort in the face of increased driving demands, and to improve safety by reducing the hazards arising from driver under-performance" [1]. Research conducted in this field has demonstrated that the implementation of many ADAS could be substantially simplified when introducing digital maps, like those used by navigation systems, yet featuring expanded content. Using this statement as a basis, several research projects have investigated the technical feasibility of such enhanced digital mapping. In Europe, the Nextmap consortium [6] has completed a two-year project funded by the European Union (EC/DG XIII) and results have shown that enhanced map databases, coupled with accurate descriptions of road geometry plus additional content (e.g. road lanes, speed limits, traffic regulations), are technically feasible and enable generating various map-based vehicle applications that provide support for the driving task under both safe and comfortable conditions.

The SafeMap project [2], which is part of the DEUFRAKO program (a cooperation programme between France and Germany, which supports cross-national network activities, funds joint projects and launches joint calls for proposals), aims at assessing the use of a dedicated digital map for road safety applications. The consortium includes car and trucks manufacturers (Daimler Chrysler, PSA Peugeot Citroën, Volvo 3P/Renault Trucks), Map providers (TeleAtlas, Navteq), Universities and other research agencies (LCPC, Univ. Paris 5, Bast, ISIS…). More precisely, the objectives are to define the database content in regards to safety, benefits and data provision costs, to assess the feasibility of map data provision, to optimize the data provision chain (public authorities and private companies contributions), to provide a demonstrator with this system embedded and to evaluate in-vehicle safety applications using digital maps.
According to the two criteria of safety effectiveness and ease of implementation/deployment, the SafeMap consortium has been conducting assessments of the six following functions:

(A) *Speed Limit Assistant:* This function is similar to the various systems studied during the series of Intelligent Speed Adaptation initiatives across Europe. The legal speed limit information should cover the entire rural road network as well.
(B) *Frequent Accident Spot Warning:* Whenever current driving conditions correspond with a combination of accident circumstances that have already been produced on a given road section, a warning is delivered to the driver.
(C) *Overtaking Assistant:* This function warns the driver whenever an intended maneuver to overtake another vehicle is either prohibited or risky.
(D) *Hazardous Area Identification:* Identification of dangerous curves and junctions based on road characteristics.
(E) *Intersection Approach Speed Warning:* The appropriate speed for approaching an intersection is computed onboard, based on both map data and the particular driving situation.
(F) *Curve Speed Warning:* Safe speed when negotiating a curve is computed from map data, which takes into account road characteristics, vehicle dynamics and driver behavior.

Although safety benefit estimates of ADAS have been the focus of a large body of literature over the past ten years [i.e., 7], little human factors-based research on drivers' behavior or safety impact of ADAS systems has been conducted. A few published studies indicated, for example, that alarm systems help direct driver attention to safety traffic conditions [3; 8]. Other studies found that collision-warning systems helped drivers to estimate headway more accurately and, consequently, drivers maintained longer and safer headways [4]. But these are only a few.
The aims of the present study were to assess the impact of warnings on speed and to evaluate the acceptability of the SafeMap warnings as implemented by Volvo 3P/Renault Trucks:
(A) *Speed Limit Warning,*
(B) *Curve Speed Warning,*
(C) *Frequent Accident Spot Warning,*
(D) *Physical restrictions warning*.

METHOD

Participants

Participants were 14 licensed drivers (men) ranging in age from 36 to 57 years old (M = 51,0; SD = 6,0). Drivers were trucks test drivers and were recruited on a voluntary basis. They were all experienced with Renault trucks. Since the drivers could not be allocated to one of two groups *a priori* on the basis of their characteristics, they were allocated as a function of their order of participation (see Table 1).

Table 1.
Type of drivers by group

Profession	*Gr. 1*	*Gr. 2*
Mechanic test drivers	4	2
Technician test drivers	2	4
Adjusters test drivers	1	1
Total	7	7

The two groups differ statistically in terms of age (t (13) = -2,49; p = 0,03). The mean age was 47,5 years old (SD = 6,4; *range* = 36-55) for the participants in group 1 and 54,5 years old (SD = 2,6; *range* = 49-57) for the participants in group 2.
No statistical difference was observe between groups in terms of number of years of heavy weight truck driving (t (13) = -0,52; p = 0,62). Participants had 25 (SD = 9,1) and 28 (SD = 10,6) years of experience in group 1 and 2 respectively.
Most of the drivers used to drive everyday (Table 2). The two groups were not statistically different on this aspect (χ^2 (1; N = 14) = 0,00; p > 0,05) but differ in terms on number of kilometers participants covered in the past twelve months (χ^2 (1; N = 14) = 4,98; p < 0,05) (Table 3). Participants in group 1 traveled more kilometers than the participants in group 2. Only 1 driver was used to use a GPS and none of the participants use an in-vehicle information system.

Table 2.
Frequency of driving

Frequency	*Gr. 1*	*Gr. 2*
Once/month to Once/week	1	2
Everyday	6	5
Total	7	7

Table 3.
Kilometers covered during the last twelve months

Kilometers	*Gr. 1*	*Gr. 2*
< 10 000	2	7
10 000 – 50 000	5	
Total	7	7

Apparatus and materials

Vehicle and warning display – The vehicle participants were invited to drive was a Renault Magnum. The SafeMap warnings were presented on a display located on the dashboard as illustrated in Figure 1. The display was 9,2 cm high and 15,5 cm wide.

Figure 1. View of the Renault Magnum dashboard with the warning display.

<u>SafeMap warnings</u> – The warnings that were presented to the drivers consisted in speed, curve, accident spot and physical restriction warnings. Two warnings could be displayed at the same time but at different locations and size depending on priority rules. Figure 2 illustrates two warnings, one, in the central position, indicating that the driver is exceeding speed and another one on the upper left corner indicating an accident spot. In this example, the speed warning has priority over an accident spot warning.

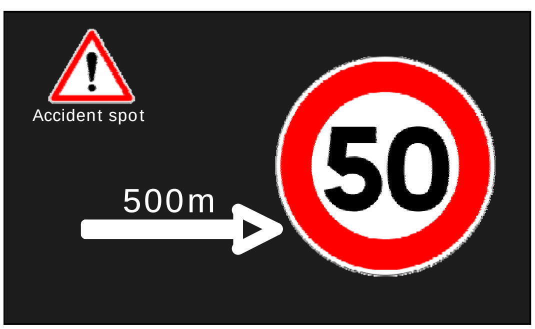


Figure 2. Example of a dynamic display of warnings.

<u>The test track</u> – The test track was located in the vicinity of the Lyon region. In consists of about 60 km and was chosen so as to ensure that a sufficient number of warnings would be triggered.

<u>Data collection</u> – Two small webcam were use: one to record the warnings displayed and another one to record the drivers' face so as to be able to see whether the drivers were looking or not at the warnings when they were displayed. The video images were recorded with the software CANape 6.0 which was installed on a portable PC. This PC was connected to the CAN bus of the truck. Thus, the position of the truck on the circuit in terms of distance traveled, speed, break pedal pressure, steering wheel angle, longitudinal acceleration as well as the code of the SafeMAP warnings displayed were recorded in real time simultaneously and unobtrusively.

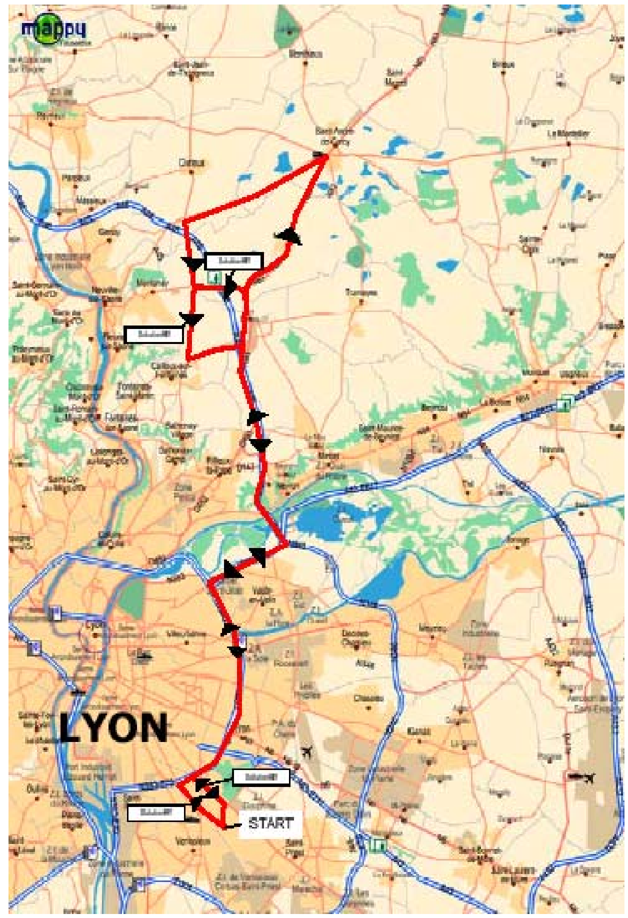


Figure 3. Route of the test track near Lyon, France.

<u>Interview and questionnaires</u> – To evaluate drivers' acceptance of the warning system as well as getting subjective information on its characteristics, a questionnaire and a survey were administered immediately after the driving session. To measure the subjective assessments of usability, we used a modified version of the "System Usability Scale (SUS)" [5] a simple ten-item Likert scale. Drivers were also asked to assess the system on several pairs of adjectives describing the characteristics of the system on a bipolar scale ranging from -2 to 2. As for the survey, we used another questionnaire on different characteristics of the warning systems (position of the display, size of the warnings, frequency, etc.), with questions on the understandability of the warnings as well as their dynamics.

Procedure

All the driving sessions occurred at daytime under good weather conditions (dry weather).
At the arrival at the start point of the circuit, the recording equipments were switched on and the instructions were given to the drivers. We used a mixed design with “Group” as a between factor and “Run” as a within factor (Table 4). All the drivers traveled the circuit two times. For the drivers in group 1, the first run was done with the warning system off. Thus no warnings were presented to the drivers during their first run. For the drivers in group 2, the first run was conducted with the warning system on. Thus, depending on the drivers’ behaviors and the location of the vehicle on the circuit, drivers could be presented with warnings. Although only the drivers in group 2 had the opportunity to experience the warning system on the first run, the behaviors of all the drivers were recorded continuously. After the first run, participants were invited to travel the circuit a second time. This time, the warning system was turned on for the drivers of group 1 and turned off for the participants of group 2. After the drive session, the questionnaires were administered to the drivers and an interview followed.

Table 4.
Warning system state

	Warning system state	
Group	*1st run*	*2nd run*
1	Off	On
2	On	Off

RESULTS

The effects of speed warnings on drivers’ behaviors

Speed warnings were dependent on the drivers’ behaviors. As such, speed warnings were only displayed when drivers exceeded the legal speed limits (50 km/h and 70 km/h). Thus, for each driver, the warnings appeared at different points on the circuit and for different durations. To be able to compare and analyze statistically the data between and within groups, the data files were filtered so as to keep only the data that were recorded without any loss or interruptions for each driver on the two runs.

Then, different measures were computed such as the number of speed excess per minute and mean duration of the speed excess. The multivariate analyses of variance for repeated measures (MANOVA) indicate that there were no statistical effects for the group (F (1, 27) = 0.79, p = .393) and run (F (1, 27) = 0.18, p = .683) factors and no interactions between them (F (1, 27) = 1.18, p = .298) on the number of speed excess per minute.

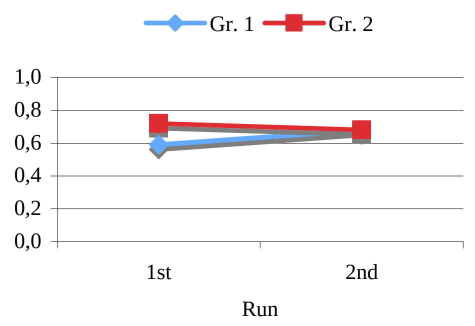


Figure 4. Number of warnings per minute for each group ruding the first and second run.

In other words, whether speed warnings were displayed or not had no effect on the number of speed excess. On the average, participants in group 1 exceeded legal speed limits 0.64 times per minute while participants in group 2 exceeded legal speed limits 0.7 times per minute. The data also indicate that drivers were quite coherent in the way they drove from the first to the second run. Globally, drivers exceeded speed limits 0.66 times per minute during the first run and 0.68 times per minute during the second run.
However, the display of the speed warnings had an effect on the duration of the speed excess. Although the MANOVA for repeated measures did not revealed a significant effect for group (F (1, 27) = 0.06, p = .807) and for run (F (1, 27) = 2.20, p = .164) factors, it revealed a significant effect of the interaction between the group and run factors (F (1, 27) = 9.91, p = .008) as illustrated in Figure 5. What the interaction shows is that drivers exceeded the legal speed limit for shorter period of time when they were warned about their speed limit excess as indicated by the post-hoc comparisons (F (1, 27) = 5.53, p = .027). Thus, duration of speed excess is shorter when drivers are warned, i.e. in the second run for drivers in group 1 (F (1, 27) = 5.99, p = .022) and shorter in the first run for drivers in group 2 runs although not statistically different (F (1, 27) = .77, p = .388).

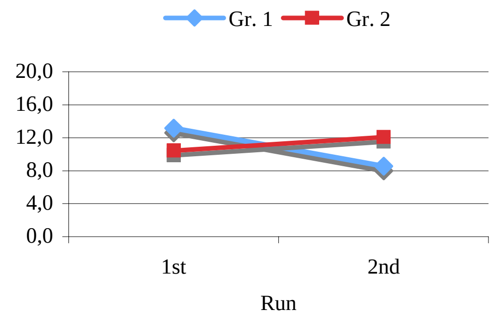


Figure 5. Mean duration of speed excess for each group during the first and second run.

The statistical differences found for the duration of speed excess is in fact due to the excess in speed for the legal limits of 70 km/h. Figure 6 illustrates the evolution of the duration of speed excess for each group during the first and second run for a 50 km/h legal limit. The MANOVA indicates no statistical effects for the two factors {group: (F (1, 27) = .97, p = .343); run: (F (1, 27) = .78, p = .394)} and their interaction (F (1, 27) = 1.64, p = .224). In other words, there is no statistical difference in terms of duration of speed excess whether the warnings are presented or not. The small decrease observes in group 1 is not statistically significant.

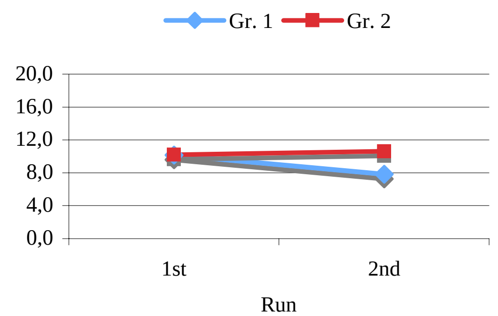


Figure 6. Mean duration of speed excess for each group during the first and second run for a 50 km/h legal limit.

However, the MANOVA for repeated measures computed on the duration of speed excess over 70 km/h showed a significant effect for the interaction of the group and run factors (F (1, 27) = 6.50, p = .026) (see Figure 7). On the average, the duration of speed excess is shorter (M = 10,85 s) when speed warnings are presented to the drivers (group 1, 2nd run and group 2, 1st run) in comparison to the runs were drivers are not warned (group 1, 1st run and group 2, 2nd run) for their speed excess (M = 17,80) (F (1, 27) = 4.52, p = .044).

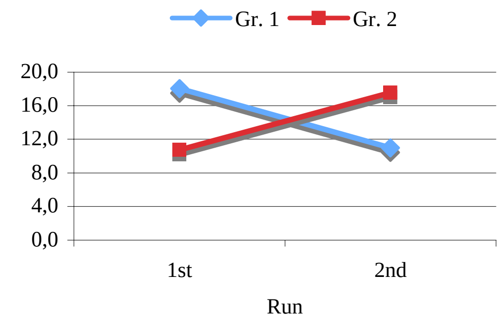


Figure 7. Mean duration of speed excess for each group during the first and second run for a 70 km/h legal limit.

The effects of curve warnings on speed

When the warning system was on, speed warnings were displayed when the actual speed exceeded the recommended speed calculated so as to ensure safety of the convoy given the curve geometry. For each driver, the speed was recorded continuously whether the warning system was on or not, thus allowing the assessment of the impact of the warning in comparison to the run during which the warning system was off.

Here again, the data files were filtered so as to keep data that could be compared for the 12 curves among all the drivers across the two runs. Two indexes were computed: (1) the percentage of the distance traveled in speed excess (with and without warnings) of the distance of the run, (2) and the percentage of distance traveled in speed excess (with and without warnings) of the cumulated distance of the 12 curves.

The MANOVA for repeated measures did not revealed any statistical effects. There was no effect of group (F (1, 27) = .28, p = .607), no effect of run (F (1, 27) = 1.98, p = .185) and no interaction (F (1, 27) = 2.26, p = .159) in terms of percentage of the distance traveled in speed excess of the distance of the run (Figure 8, Gr. 1 and Gr. 2). The same statistical conclusions are drawn for the percentage of distance traveled in speed excess of the cumulated distance of the 12 curves: there are no statistical differences between groups (F (1, 27) = .47, p = .505), between runs (F (1, 27) = 1.87, p = .197) and no statistical interaction (F (1, 27) = 2.03, p = .179). In other words, the curve warnings had no statistical effects on speed. Drivers' behaviors in curves did not differ from one run to the other with and without the curve warnings.

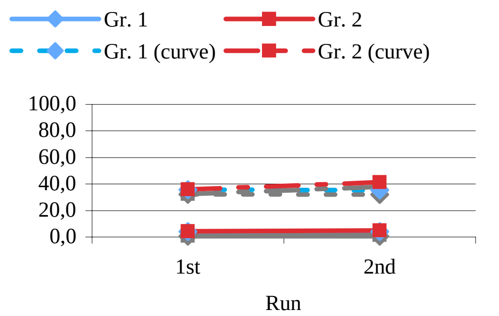
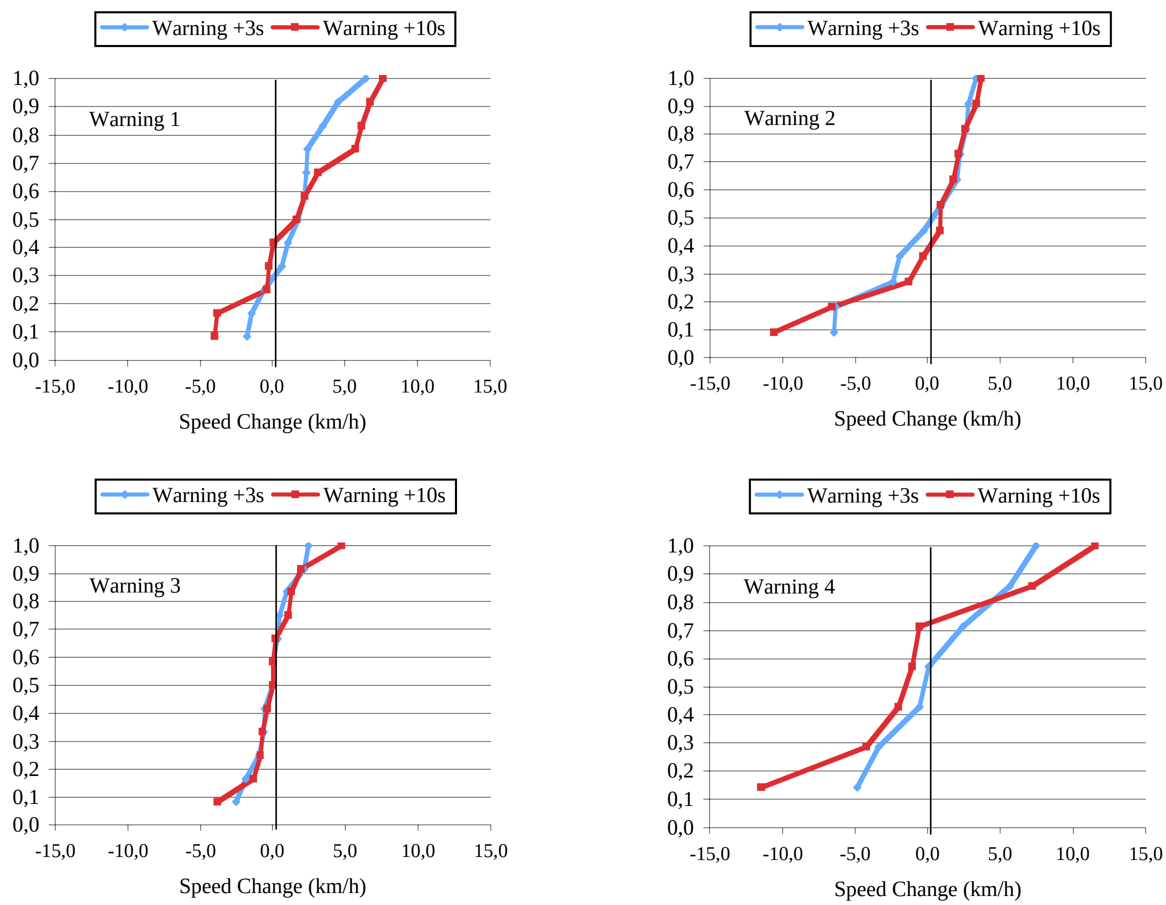


Figure 8. Percentage of distance traveled in speed excess.

The effects of accident spots warnings on speed

Six accident spots were analyzed. For the analysis, the speed of the truck was considered, from 10 s prior to the accident spot (whether the warning was displayed or not) to 10 s after it. To assess the impact of the warning we: (1) compared the time period before the warning to identify any general change in speed between the two runs for each driver, (2) compared the time period after the display of the warning to identify a change in speed after the warning was displayed, (3) subtracted the general speed change from the speed change after the warning was displayed to isolate the effect of the accident spot. Two time period were considered for the analyses after the warning points: 3 s and 10 s. The figures that are presented hereafter (**Figure 9**) concern only the drivers that were unaffected by cars ahead.



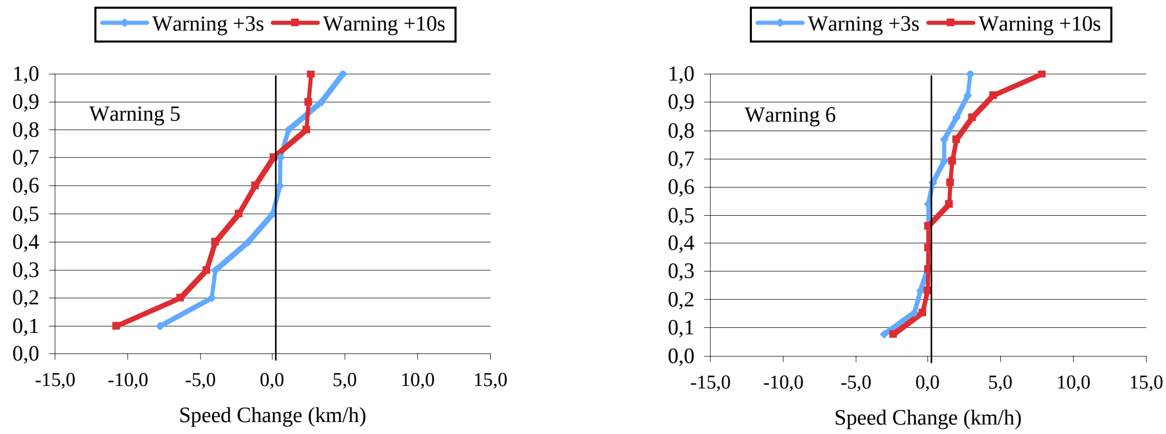


Figure 9. Cumulative percentage of absolute speed change 3 and 10 s after the accident spot warning onset.

These graphs show that the impact of the accident spots warnings on speed is variable from one accident spot to another and that the variations in speed, i.e. decelerations and accelerations vary among drivers. For example, the accident spot warning number 3 induced, 3 s after its onset, a decrease in speed ranging from 0.56 to 2.55 km/h in 42% of the drivers. On the other hand, 42% of the drivers increased their speed from 0.34 to 2.43 km/h. This tendency is almost the same 10 s after the onset of the warning. On other accident spots, the decrease in speed for some drivers and the increase in speed for others is greater as illustrated for warnings 2, 4 and 5. In other words, the characteristics of the road at these accident spots may have increased the effect of the warnings. When the tendency of drivers to decrease their speed continues after 3 s, the red lines on the figures are above the blue ones.

The effects of physical restrictions warnings on speed

Two physical restriction warnings were also analyzed in terms of the impact they had on speed. The approach taken to present the results is identical to the approach adopted for the accident spots warnings. As for the accident spots, the impact of the warnings on speed varies as a function of the driver. As shown in Figure 10, three seconds after the onset of the warnings a decrease in speed between 0.79 km/h to 4.57 km/h was observed in 44% of the drivers on the first physical restriction (PR 1). However, 56% of the drivers increased their speed from 0.57 km/h to 4.92 km/h. The decrease in speed continued after 3 second, and 10 seconds after the onset of the warnings, 67% of the drivers had decreased their speed between 0.86 to 6.92 km/h. The other 33% of the drivers, although they were above the speed they had before the onset of the warning were "slowly" decelerating, as indicated by the upper part of the red line in Figure 10, PR 1.

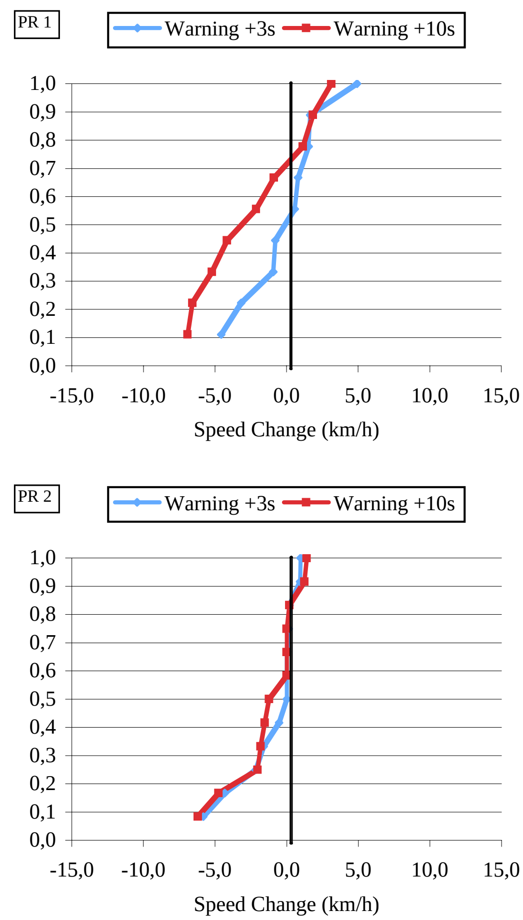


Figure 10. Cumulative percentage of absolute speed change 3 and 10 s after the physical restriction (PR) warning onset.

On the second physical restriction (PR 2), a decrease in speed ranging from 0.52 to 5.81 km/h was observed in 42% of the drivers 3 s after the onset of the warning. In this second physical restriction area, warnings had no effect in speed in about 30% of the drivers. The other drivers (28%) showed a very slight increase in speed ranging from 0.13 to 0.97 km/h. Ten seconds after the onset of the warning, 83% of the drivers kept their speed constant or continued to decrease it from 1.22 km/h to 6.2 km/h.

Drivers' assessments of the warning system

Results of the adjective pairs questionnaire - After the test runs, drivers were invited to complete two scales. The first was used to assess the system on 9 pairs of adjectives. To get the drivers' attention to the pairs of adjectives, the positive and negative items were randomly changed from right to left. Figure 11 presents the mean scores on each pair of adjectives. Here the positive items are presented on the right.

As is illustrated in this figure, the evaluation is rather positive although some pairs of items got only small positive judgment. Drivers judged the system useful, good and desirable. However, the system received a low score on its helpfulness and activating aspects. Nonetheless, no pairs of adjectives got negative scores.

The System Usability Scale results - To measure the usability of the system, drivers were invited to complete a modified version of the "System Usability Scale" (SUS). The SUS was modified because the system being evaluated was not an interactive system in the usual sense. Drivers could not interact with it. Thus some statements of the SUS were modified so as to be more adapted to the warning system. The results of this scale are illustrated in Figure 12. As with the previous results, all the drivers' positions with respect to the statements are positive. The scores that are lower than 0 concern negative statements. In other words, disagreeing with a negative statement means agreeing with its positive counterpart. For example, on the average, drivers said they rather disagreed with the statement saying "They found the warnings difficult to understand" (-1). This result is thus positive. All the scores except one, which is 0, are positive. Scores that are equal or higher than 1 concern 4 statements out of 10. These statements concern the understandability of the warnings, the context of use of the warning system, the non-nuisance character of the system, and the learnability of the system.

Figure 11. Results of drivers' survey of the system.

In other words drivers found the system rather easy to learn and understand. They said they would use the system even in vehicle they are familiar with and that the warnings constitute no nuisance. With scores that were lower, drivers said the system was not superfluous, the warnings adequately reflected the situations encountered and that they were well informed. However, the mean score to the statement "I drove more safely with the system" was 0.

CONCLUSION

The aim of this research was to assess the impact of speed limit, curve speed, frequent accident spots and physical restrictions warnings on driving and to evaluate the drivers' acceptability of these warnings. The results presented in this paper indicate that the speed limit warnings had no effects on the number of times drivers exceeded speed limits but decreased the duration of the speed excess and that this effect was essentially true for the 70 km/h speed limit. The effect of curve warnings had no specific effects on speed. The accident spot warnings showed variable effects. On some accident spots, the warnings induced a decrease in speed although a small one. As for the physical restrictions warnings the effects were different for the two warnings. The range of speed decreases for some drivers but increased for others.

The comments that were collected after the test runs towards the warning system were rather positive and drivers provided good ideas to improve the warning system.

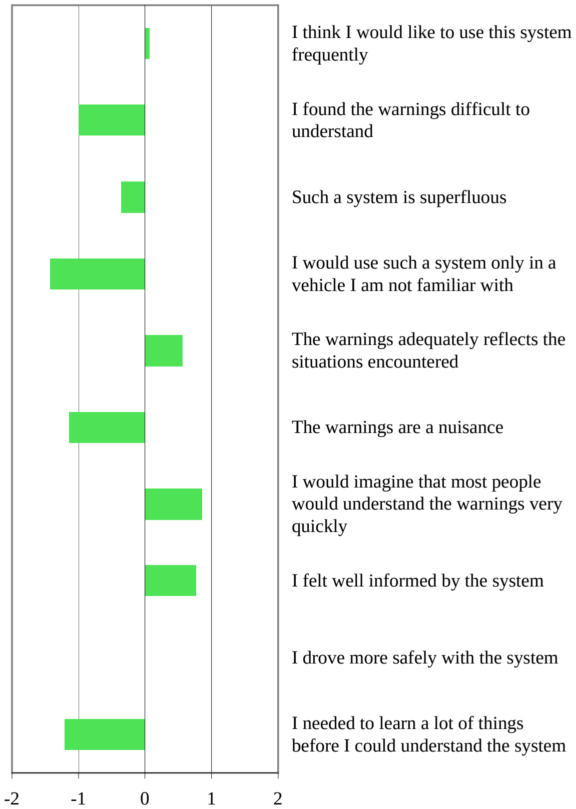


Figure 12. Drivers' mean scores to the modified version of the System Usability Scale. The original Likert scale was transformed so as to present the scores in comparison to the neutral position (0). The -2 score represent a "Strongly disagree" position while the 2 score represents a "Strongly agree" position with respect to the statement.

Although the impact of the warnings on speed may not be as high as one would have liked, caution should be taken before concluding. Speed may not be the best index of the warning impact: being warned of different situation may increase the attentional processes and situation awareness of the drivers without having any effect on speed. On the other hand, people react differently to warnings and if even a small portion of the drivers react with a decrease in speed, this could probably save lives. As such, the SafeMap system may be a promising tool to assist the diver in critical situations and thus avoid accidents. But such a tool would necessitates more research on the design of the warnings, its placement in the dashboard and its acceptability.

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