

Experimental Study on Different HMI Design Options for Lateral Safe Applications

**Evangelos Bekiaris¹, Vassilis Papakostopoulos¹, Maria Gemou¹,
Evangelia Gaitanidou¹**

¹Centre for Research and Technology Hellas / Hellenic Institute of Transport
6th Km Charilaou-Thermi, 57001 Thessaloniki, Greece

Tel: +30 210 9853194, Fax: +30 210 9853193

abek@certh.gr, vpapak@certh.gr, mgemou@certh.gr, lgait@certh.gr

Abstract:

LATERAL SAFE is a subproject of the PREVENT Integrated Project co-funded by the European Commission under the 6th Framework Programme. LATERAL SAFE introduces a cluster of safety applications of the future vehicles in order to prevent lateral/rear related accidents and assist the driver in adverse or low visibility conditions and blind spot areas. LATERAL SAFE applications include a lateral and rear monitoring system (LRM), a lane change assistance (LCA) and a lateral collision warning (LCW). An effective Human Machine Interface (HMI) is foreseen in each case to support these applications. For this reason, pilots have been organised in three sites (one in Greece and two in Sweden) to evaluate alternative HMI mock-ups towards the determination of the most adequate one for each LATERAL SAFE application.

The Greek HMI Pilots were conducted at a semi-dynamic driving simulator and targeted at the evaluation of the HMI for the LCA and the LCW applications. A mixed factorial design 3x3 of within and between subjects was used and all subjects run a set of 5 traffic scenarios, firstly without receiving any warning, and then another set of 5 traffic situations, by receiving a particular type of warning(s) depending on the experimental condition.

In this paper, the experimental plan designed for the Greek HMI Pilots, the specific HMI alternatives evaluated as well as the main results arisen will be presented.

Keywords:

lateral safe, HMI, simulator scenarios, objective and subjective evaluation measures, level of explicitness of warnings.

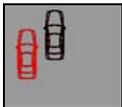
1. INTRODUCTION

The selection of the HMI alternatives that were evaluated in Greek Pilots, was based on two fundamental ergonomic principles, namely the principles of *compatibility* and *visual clarity*, as well as consideration of *driver's available resources* (Jordan, 1999). Furthermore, regarding cautionary warnings an additional important aspect considered was the determination of the *required level of explicitness* of the cautionary warnings that were visually displayed to the side mirror(s).

In regard to **cautionary warnings** the most appropriate type of warning was considered to be the visual one, taking into account the particular driving tasks and driver's available resources. Regarding **imminent warnings**, apart from the visual warnings displayed on the side mirror(s), using both visual and auditory warnings that would be displayed on the rear view mirror was considered necessary. The reason is that a driver who has already received a cautionary warning from side mirror(s) and had not taken action, he/she may be "blinded" to perceive the displayed information (a quite often reported cause in traffic accident reports, namely "looked, but failed to see"), or he/she maybe momentary distracted (Rumar, 1990; Levin and Simon, 1997). In both cases, the driver has failed to receive the visual displayed information to the side mirror(s), thus, there is a need to redirect his/her attention through additional warnings that will be displayed on the rear view mirror.

Having clarified the appropriate sensory modalities for imminent and cautionary warnings, the particular types of warning symbols were decided on the basis of the above mentioned principles (Table 1).

Table 1. HMI alternatives for the cautionary warnings according to the level of explicitness of the information conveyed through the used warning symbols. Numbers in cells indicate the number of traffic events under which a particular warning symbol could be produced.

Symbols of Warning	Level of explicitness of cautionary warnings		
	A High	B Moderate	C Low
(a) Triangle 	1	2	3
(b) Configuration with leds 	1	2	3
(c) Two vehicles in parallel 	1	2	3

Respectively, the imminent warnings evaluated were the following:

- ◆ an auditory warning (a beep, indicating imminent danger, in general), and
- ◆ a visual warning (three lights, two for the left/ right side of the vehicle and one for the area behind it), in order to direct driver's focus of attention to the appropriate road area.

The visual warning used for the imminent case is presented below (Figure 1). The acoustic warning used in the trials was a Wierwille sound.

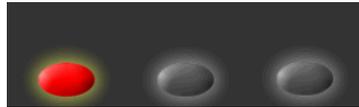


Figure 1. Imminent warning implemented below the central mirror in the HIT simulator.

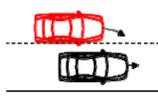
2. EXPERIMENTAL DESIGN

2.1 Simulation of the LATERAL SAFE LCA, blind spot and LCW systems

The typical traffic scenarios that have been tried in the HMI tests, are: (a) *lane change-1*, where the driver of the **subject vehicle** (the black one) intends to enter into a lane which is occupied by another passing vehicle, (b) *lane change-2*, where the driver of the **subject vehicle** (the black one) intends to enter into a lane whilst another vehicle is stagnating on the blind spot of the subject vehicle and (c) *drifting of another vehicle* to the lateral area of the subject vehicle whilst driver moves on his/her lane. These traffic scenarios are graphically presented in the following table.

Table 2. Related warning systems and type of warnings (imminent vs cautionary) in respect to traffic situations and relative position of other vehicles.

Traffic scenario	Related warning system	Danger of incident risk	
		Cautionary warning	Imminent warning
<p>(a) Lane change-1</p>	LCA	TTC = 4sec	TTC = 1sec
<p>Lane change-2</p> <p>(stagnation to the blind spot)</p>	LCA-blind spot		

		Danger of incident risk	
		TTC = 4sec	TTC = 1sec
<p>(c) Drifting of another vehicle</p> 	LCW		

The following 5 traffic scenarios were presented within each test ride, addressing the above cases (Table 2).

Lane change imminent: The driver has to overtake a very slowly moving truck, while on the left lane there is a row of vehicles moving at 70km/h and at a distance of 20 m. This condition generates more imminent warnings, as the time gap of the vehicles row is short (~ 1 s).

Blind spot: A vehicle stagnates at the blind spot of the ego vehicle. After a while there is a very slowly moving truck on the right lane and the ego vehicle has to successfully overtake it. This scenario was to generate both imminent and cautionary warnings. The imminent warnings were generated in case of lane change intention.

Drifting imminent: A vehicle in the left lane suddenly starts drifting towards the ego vehicle with a lateral velocity of 1.5 m/s.

Lane change cautionary: The driver has to overtake a very slowly moving truck, while on the left lane there is a row of vehicles moving at 60km/h and at a distance of 30 m. This condition generates more imminent warnings, as the time gap of the vehicles row is longer (1.8 s).

Drifting cautionary: A vehicle in the left lane suddenly starts drifting towards the ego vehicle with a lateral velocity of 0.5 m/s.

2.3 Experimental plan

A mixed factorial design 3x3 of within and between subjects was used. The two independent variables were: (a) warning symbols used, with three values (“triangle”, “vehicles in parallel”, “leds”), and (b) level of explicitness of the warnings, with three values (high, moderate, low), according to the symbols’ coding for identifying the relative position/trajectory of the other vehicle. The possible combinations are summarized below.

Table 3: Experimental groups and different warning symbols’ coding depending on their explicitness about the relative position/ trajectory of other vehicles (BS: other vehicle stagnating to the blind spot; LC: lane occupied by row of passing vehicles; D: another vehicle is drifting).

Warning symbols	Level of explicitness of cautionary warnings								
	High			Moderate			Low		
	BS	LC	D	BS	PV	D	BS	PV	D
Triangle (a)	▪	(b)	(c)	▪		(b)	▪		
	▪	(c)	(b)	▪		(c)	▪		
Configuration with leds (b)	▪	(a)	(c)	▪		(a)	▪		
	▪	(c)	(a)	▪		(c)	▪		
Two vehicles in parallel (c)	▪	(a)	(b)	▪		(a)	▪		
	▪	(b)	(a)	▪		(b)	▪		
Experimental groups	Group 1			Group 2			Group 3		

In total 3 experimental groups were used. Within Group 1, each of the three possible causes for system provision of a cautionary warning was indicated by a different warning symbol. Within Group 2, there was a more generic discrimination of traffic situations and warning symbols (discrimination between lane change driving task, irrespectively of the relative position of the other vehicle, and drifting of the other vehicle). Finally, within Group 3, a single warning symbol was provided in any case of traffic danger. In total, 18 subjects, 10 male and 8 female were randomly assigned into the three experimental groups (6 subjects per group). Subjects were randomly allocated to groups. All subjects performed four sessions, two with the system providing warnings and two with the system not providing warnings, as follows:

Table 4. Subjects allocation.

	Ride 1	Ride 2	Ride 3	Ride 4
Subject i	No warning	Warning	No warning	Warning
Subject i+1	Warning	No warning	Warning	No warning

3. EVALUATION PARAMETERS AND PROCESS

The question of interest with regard to HMI alternatives evaluation was to determine:

- ◆ how driver behavior is affected in case of an imminent or a cautionary warning,
- ◆ which is the appropriate level of explicitness for the visual displayed cautionary warnings to the side mirror(s), and finally which is the most appropriate HMI according to users estimations and their performance data (recorded in simulator log files) for each traffic scenario tried, taking into consideration their relevance to the LS applications, as shown in Table 2.

The dependent variables for evaluating driving performance were:

- ◆ number of received warnings and level of compliance;
- ◆ number of accidents or successful manoeuvrings;
- ◆ minimum TTC and headway values when performing a manoeuvre;
- ◆ timing for taking an evasive action in case of other vehicle drifting.

Before the test rides subjects had to complete the consent form, a pre-test personal data questionnaire and a pre-test HMI acceptance questionnaire. After the test ride subjects

had to complete an HMI assessment questionnaire, a post-test HMI acceptance questionnaire and a NASA-TLX workload questionnaire. The supervisor completed after the test a questionnaire assessing the subjects' performance and acceptance.

4. RESULTS

The users' ratings have been classified per characteristic scenario performed, addressing respectively the three LS applications (LCA, LCA-BLIND SPOT and LCW), per parameter (objective and subjective) evaluated and per HMI tested per case. The most significant results for cautionary and imminent warnings respectively are presented below.

In the context of cautionary warnings, the "cars" symbol in the side mirror has been rated positively according to the most evaluation parameters for the blind spot scenario, which was used to address the LCA-Blind Spot application. On the other hand, the "triangle" seems to be the most appropriate from the users' aspects for the drifting scenario addressing the LCW application. The same is valid also for the lane change scenario addressing the LCA application. The "light" is not the most preferable option in most cases and it was noted that the light does not represent a specific risk, thus it creates confusion, whereas the "cars" symbol is strongly not recommended for the drifting scenario corresponding to the LCW application (quite unexpected result). In the total sample, the "light" was the less likeable of cautionary warnings and the "triangle" the most likeable. The scenario did not have a significant effect on the ratings of the "triangle" and of the "light". In specific for the "cars", the scenario had a significant effect.

In general, the HMI used in HIT tests for the imminent warnings additionally to each of the HMI tested for the cautionary warnings has not collected positive users' ratings by average. Especially, the "central mirror light" is considered rather inappropriate in all scenarios cases and would have no impact at all, as stated during the evaluation, if there was no warning sound additionally.

In addition to the subjective ratings, the results derived from the users' performance data measurements, are no less significant for the formulation of some more holistic conclusions concerning the HMIs impact on driving behaviour but also safety. The most significant conclusions coming from the results processing is the fact that the crashes regarding lane change and blind spot scenarios are less with warnings, while the crashes in the case of drifting scenario are less without warnings. It seems also that there is no effect of the system on number of accidents and on number of successful lane changes. Moreover, in the total sample, in the "triangle" group and in the "cars" group, the average reaction time was less with warnings. In the "light" group the reaction time was greater with than without warnings, which also complies with the subjective ratings' results. The average reaction time is higher with the light than with the triangle, while the reaction time with cars is the lowest. Again, the "light" HMI seems to be the less intuitive from each aspect. In parallel, in the total sample, and within each group, the average and the maximum speed during the lane change was less

with warnings and within each group. This is more evident in the “triangle” group. However none of these differences is significant.

Another result, which is really significant, is that in the total sample, and within each group, the minimum headway to the forward car during the lane change was enhanced with warnings, whereas at the same time, in the total sample and within the “triangle” group, the minimum headway to the backward car during the lane change was enhanced with warnings, without significant variations between them except from “cars” warning. Despite the fact that especially in the “light” and “cars” group the average minimum headway is not affected, it seems that the system, interfaced though the specific HMIs, has a positive impact on driving behaviour and safety.

The same is also noticed in the minimum TTC to the forward car during the lane change, which was enhanced in the total sample, and within each group, especially in the case of “triangle” group. In the total sample, and within the “triangle” and “light” group, the minimum TTC to the backward car during the lane change was enhanced with warnings. In the case of “cars”, the minimum TTC to the backward car is reduced with warnings.

In general, it seems that there is not significant change according to each experimental group concerning the results, which means that the users’ were not affected in the evaluation of the HMIs they tested, if they had tried one, two or both three alternative systems per scenario, which rather strengthens the validity of the results presented above. It also seems that the scenario itself is a significant factor, mostly in the “cars” rating, whereas the same is not valid for the “side light” and the “triangle”.

In general, the variations in the users’ ratings before and after the system’s use are not such significant, which makes us conclude that the system may have a positive impact in general; however not significant one. In fact, even in subjective ratings; fewer subjects select the negative effects after the ride. Finally, it should be also underlined that the above presented results should be filtered via the consideration that the use of the simulator may have an effect on the users’ ratings (both subjective and objective), since it cannot reflect 100% the system, which the HMIs interface in each case, although the level of immersiveness with the user is considered to be quite good.

5. REFERENCES

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