# On-Road Pilot Study on the Need for Integrated Interfaces of In-Vehicle Driver Support Systems

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**Abstract.** An on-road experiment has been performed with an equipped vehicle, to study whether the effects on driving behaviour and acceptance of a forward collision warning system and of a lane deviation warning system are different when the systems are isolated or when they are used in parallel. 24 participants were assigned in three experimental and one reference group and were asked to drive the equipped vehicle for 15 consecutive trips on a highway at similar traffic and environmental conditions. The effects of the two isolated systems improve the longitudinal and lateral driving behaviour respectively and are rated as useful and satisfactory, while the use of the systems in parallel does not have a positive effect on driving behaviour. In the latter case the systems are not considered satisfactory and cause frustration to the drivers, thus the need emerges to integrate systems and interfaces.

**Keywords:** integration of interfaces, forward collision warning, lane deviation warning, on-road study, long-term effects, evaluation.

## 1 Introduction

There exist today a variety of in-vehicle driver support systems in the market and a lot more are being developed with the primary objective to enhance the driver's ability to cope with traffic complexities. Findings from previous studies confirm that such systems can be beneficial in terms of road safety and driver's performance. For example, driving with Adaptive Cruise Control (ACC) was found to decrease speed [1,2], short time headways [3,4] and the perceived workload of a driver compared to driving without ACC [2]. A system providing warnings in case of a forward collision risk was found to reduce the number and severity of such collisions [5]. Also, a system providing lane departure warnings has been estimated to reduce the number of unintentional lane crossings by 35 % [6] as well as the number of road departure crashes in large trucks by 17-19% [7].

The above studies have evaluated the use of isolated systems, while the time of exposure to the systems is usually limited, e.g. up to four weeks for ACC [8,9].

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However, the effects on driving behaviour when using various systems in parallel may be different than the effects of isolated systems. Parallel warnings from different systems may result in driver's overload and even confusion, possibly resulting in effects adverse than the desired ones [10,11,12]. Also, system evaluation studies are mostly performed in driving simulators and not in real traffic conditions.

The objectives of the work presented in this paper were to study in real traffic conditions the effects on driving behaviour and acceptance of two systems, namely a Forward Collision Warning (FCW) and a Lane Departure Warning (LDW) system, when the systems are isolated and when they are used in parallel, and to study how effects and acceptance evolve in the long-term. To our knowledge there is no published report about a long-term on-road study of the effects from the parallel use of two systems, providing both longitudinal and lateral support.

## 2 Method

A one-way, unrelated samples experimental design was used. The independent variable was the warnings provided to the participants with three alternatives, warnings provided only by the FCW system (Group FCW), warnings provided only by the LDW system (Group LDW), warnings provided by both the FCW and LDW systems in parallel (Group Both), whereas the reference group (Group None) did not receive any warnings. During the experiment both systems were operating and the generated warnings were recorded in all four experimental conditions. However the participants were receiving only warnings according to the group to which they had been assigned. The primary dependent variable was the number of warnings generated by each system. Other dependent variables were calculated from vehicle-related measurements as explained below and subjective ratings.

In total, twenty-four experienced drivers, 14 males and 10 females, aged between 21-50 (mean=32.9 sd=7.6), participated in this study. They were holding a driving license for at least 3 years (mean=12.4 sd=6.9). Their annual mileage ranged between 5000 to 100000 km (mean=27583.3 sd=23564.7). Participants were recruited through an announcement in local newspapers. The 24 participants were equally allocated into the four groups: two groups experienced one isolated system (Group FCW, Group LDW), a third group experienced both systems in parallel (Group Both), while in the reference group participants experienced no system (Group None). To eliminate the effect of confounding variables, participants in the four groups were matched in terms of age and driving experience.

The experiment was performed using an equipped research vehicle (Lancia Thesis 2.4 Emblema), belonging to the Centre for Research and Technology Hellas, under the framework of the AIDE European project (contract IST-1-507674-IP). This vehicle is equipped, among others, with a front obstacle detection radar, a lane recognition camera, a central PC, a special central mirror with integrated warning lights, enabling the simulation of several driving assistance systems, using various activation criteria and HMI alternatives.

Two systems were simulated in this experiment, a frontal collision warning (FCW) system and a lane departure warning (LDW) system. The criterion for the activation of the FCW was:

$$D_w = (v_{driver}\, T_{driver}) + (v^2_{driver} / (2\, d_{driver}) - (v^2_{drone} / (2\, d_{drone}))\ . \quad (1)$$

where: $D_w$ [m] is the warning distance, $v_{driver}$ [m/s] is the speed of following driver; $T_{driver}$ [s] is the assumed driver's reaction time to an event set to 0.5 s for imminent warnings and to 1.5 s for cautionary warnings, $d_{driver}$ [m/s$^2$] is the assumed deceleration of the driver's vehicle (was set to 5 m/s$^2$), $v_{drone}$ [m/s] is the speed of the lead vehicle, $d_{drone}$ [m/s$^2$] is the assumed deceleration of the lead vehicle (was set to 5 m/s$^2$). When the actual distance was less than the warning distance, a warning was given in two levels, as a yellow light on the central mirror for cautionary warnings and as a red light on the central mirror plus an auditory alarm for imminent warnings. The LDW system provided a warning when the time-to-line crossing was less than 0.4 s. This system was active only for speeds greater than 50 km/h. The warning consisted of a sound, like the one heard when a vehicle drives over rumble strips.

The duration of the study was 15 weeks. After an initial familiarization trip with the research vehicle and after being informed about the systems functionalities, participants were asked to drive the vehicle once a week for 15 consecutive times along a standard route. The highway route in each trip was 79 km with a speed limit of 120 km/h., thus trip duration was around 1 hour. Additionally, each trip of the same participant took place along the same highway route and on the same day of week and time of day, so that distance travelled, traffic conditions and exposure time to the systems tested were as much as possible similar for all trips of each participant.

With this design, we collected and analysed in total 360 trips (90 trips per group, 6 trips per week per group). Trip number was used to study effects of exposure to the system(s).

## 3 Results

The following vehicle-related measurements were directly recorded from the experimental vehicle with a frequency of 10 Hz: vehicle speed, lateral position, lead vehicle distance and number of warnings generated by each system. Based on these measurements, the following parameters were calculated: mean trip speed, percentage of driving time spent at headways less than 1 s, standard deviation of lateral position, number of lane changes per trip and percentage of lane changes performed with the use of direction lights per trip. During the analysis only data recorded during the highway driving were considered, while data recorded on the roads to and from the highway were excluded from the analysis.

Separate two-factorial ANOVA's and t-tests were performed for each group combination for the total sample of 90 trips and per trip within each group.

### 3.1 Effects on Speed

The mean speed per trip in the FCW group in the total sample (90 trips) was significantly lower than in the reference group None (p=0.034). No difference was found between all other combinations of groups. There was an effect of trip number, only in the group Both (p=0.061), where we note a mean speed increase with trip number.

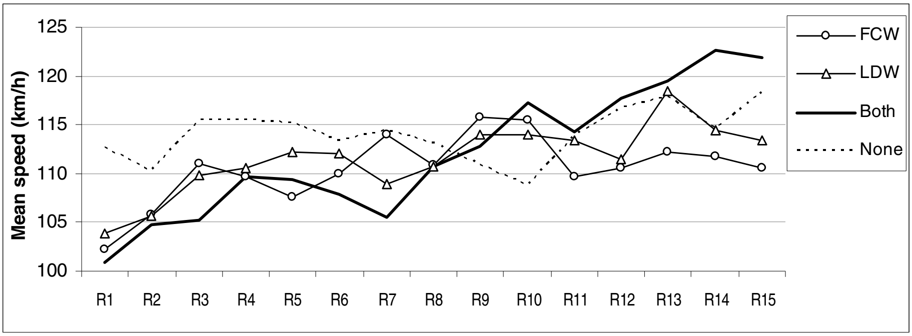


**Fig. 1.** The mean speed per trip and group

### 3.2 Effects on Longitudinal Driving Behaviour

The mean number of imminent forward collision warnings (Fig. 2) generated by the FCW system per trip was significantly lower in the FCW group than in all the other three groups (FCW / LDW p=0.001, FCW / Both p=2.063 $10^{-7}$, FCW / None p=2.559 $10^{-8}$). The mean number of forward collision warnings that would have been generated for the LDW group per trip was significantly lower in relation to the group Both (p=0.0057) and the reference group (p=0.0046). No difference was found between the Both and the reference groups. No effect of trip number was found.

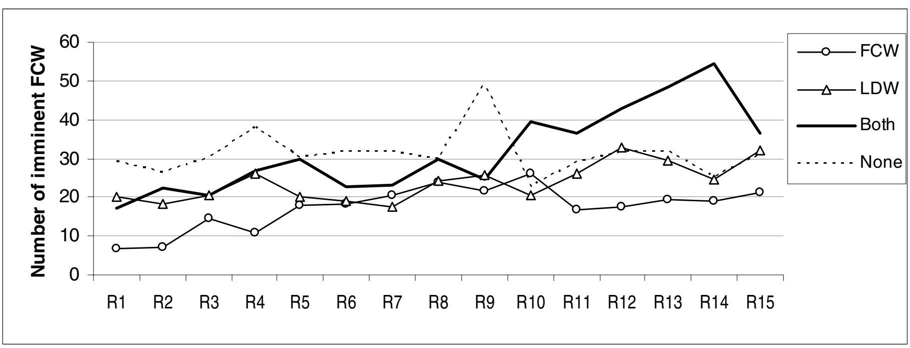


**Fig. 2.** Mean number of imminent frontal collision warnings per trip (visible/audible for the FCW and the Both groups only)

Participants in the FCW group spent significantly less time driving at short headway of less than 1 s (Fig. 3) compared to all the other groups (FCW / LDW p=0.099, FCW / Both p=2.382 $10^{-5}$, FCW / None p=0.0005). Participants in the Both group spent significantly more time driving at short headway of less than 1 s compared to all other groups (Both / FCW p=2.382 $10^{-5}$, Both / LDW p=0.018, Both / None p=0.0229). Some effects of trip number were found for the Both group (p=0.098), where the percentage of time driving at short headway increases with trip number.

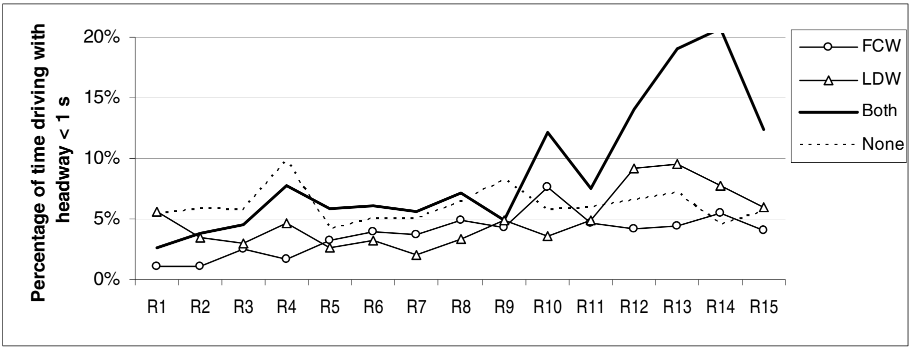


**Fig. 3.** Mean percentage of driving time at headways less than 1 s

### 3.3 Effects on Lateral Driving Behaviour

The mean number of lane departure warnings (Fig. 4) generated by the LDW system per trip was significantly lower in the LDW group than in all other groups (LDW / FCW p=3.91 $10^{-33}$, LDW / Both p=7.238 $10^{-13}$, LDW / None p=4.79 $10^{-16}$). No difference was found among all other group combinations.

The lateral driving behaviour has been examined by using the mean standard deviation of lateral position per trip and the percentage of lane changes performed with the use of direction lights. Lane positions recordings during lane changes have been excluded from the analysis regarding lateral position. Therefore, the high values of mean standard deviation of lateral position (Fig. 5) found in this study compared to the ones in the literature should be attributed to the fact that in the present study, participants were asked to drive normally and were not instructed to maintain a steady lane position while driving.

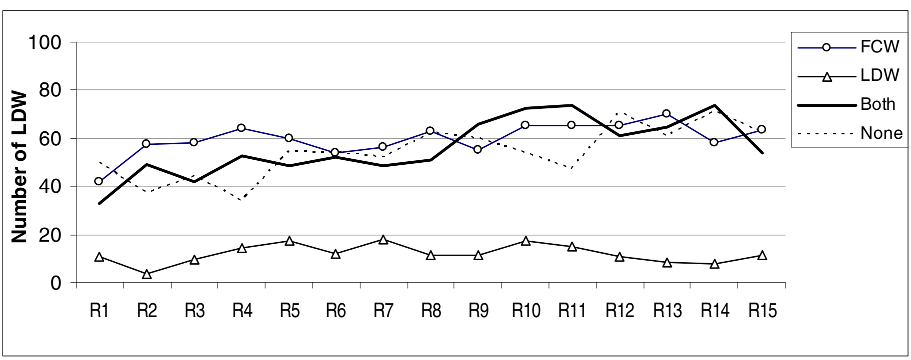


**Fig. 4.** Mean number of lane departure warnings (audible for the LDW and the Both groups only)

The mean standard deviation of lateral position per trip was significantly lower in the LDW group compared to all the other groups (LDW / FCW p=1.048 $10^{-22}$, LDW / Both p=5.687 $10^{-8}$, LDW / None p=7.564 $10^{-11}$). The mean standard deviation of lateral position per trip was significantly higher in the FCW group compared to all the other groups (FCW / LDW p=1.048 $10^{-22}$, FCW / Both p=0.00335, FCW / None p=2.285 $10^{-6}$). No difference was found among the Both group and the reference group.

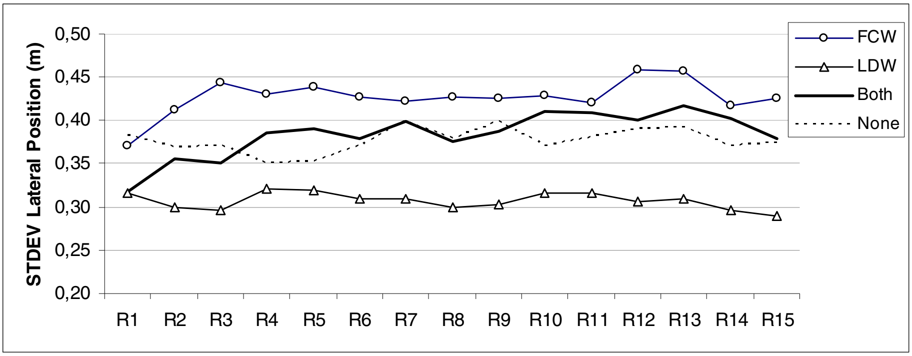


**Fig. 5.** Mean standard deviation of lateral position (distance from lane centre) per trip (excluding lane changes)

No effect of group or trip number on total number of lane changes per trip (Fig. 6) was found. Participants in the LDW group performed a significantly greater percentage of lane changes using direction lights (Fig. 7) compared to the other groups (LDW / FCW p=1.0245 $10^{-15}$, LDW / Both p=2.527 $10^{-9}$, LDW / None p=8.74 $10^{-9}$). No other difference was found among the rest groups combinations.

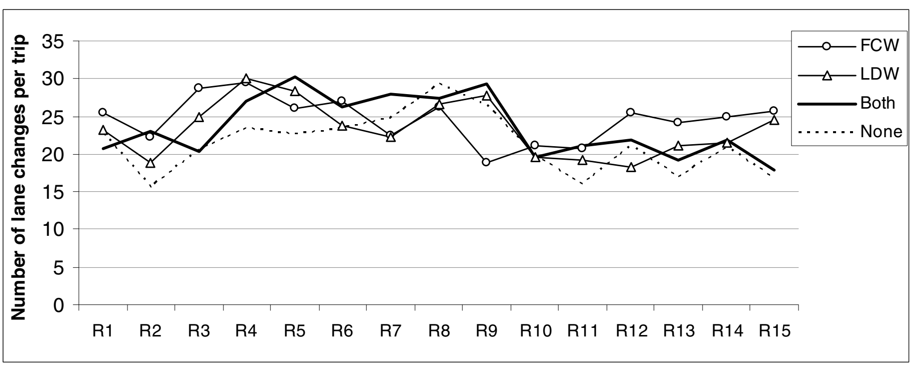


**Fig. 6.** Number of lane changes per trip.

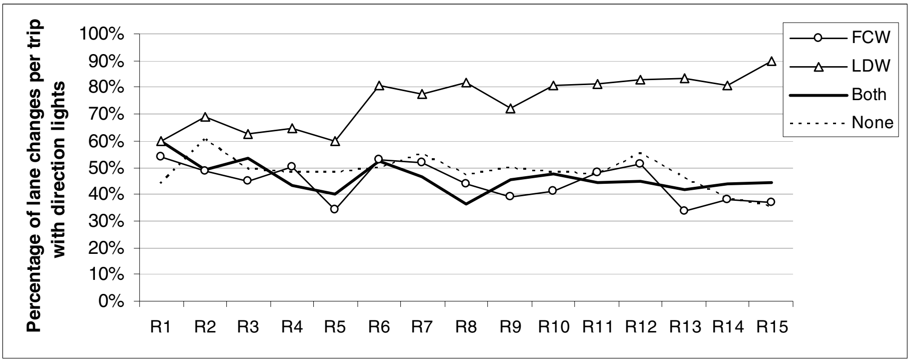


**Fig. 7.** Percentage of lane changes per trip with the use of direction lights

### 3.4 Subjective Ratings

Subjective evaluation of the system(s) experienced was done by the participants of the groups FCW, LDW and Both after the end of each trip. The acceptance scale of Van der Laan et al [13] was used, through which the participants ratings are synthesised in two dimensions: usefulness and satisfaction. Participants in the FCW and the Both groups rated the FCW system as useful (Fig. 8), the ratings are higher in the FCW group. Only participants from the FCW group rated the system as satisfactory, while participants from the Both group rated it negatively regarding satisfaction (Fig. 8), implying that the parallel use of the two systems may have caused irritation.

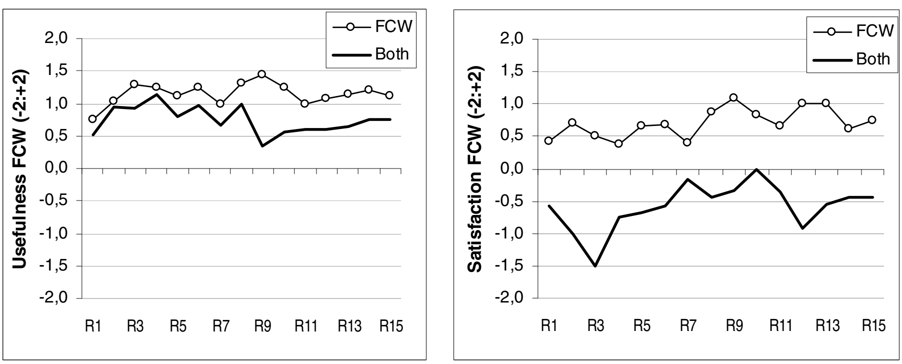


**Fig. 8.** The usefulness and satisfaction scores for the FCW system (visible and audible to FCW and Both groups)

The same was also found regarding the LDW system (Fig. 9). The participants in the LDW and the Both groups rated it as useful, but only participants from the LDW group rated it as satisfactory. The usefulness scores from the Both group are most of the times lower than those from the LDW group. The participants in the Both group have always (except from trip 10) rated it negatively regarding satisfaction.

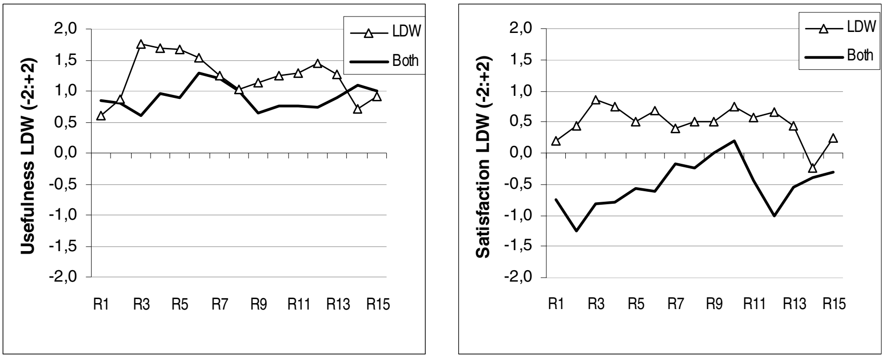


**Fig. 9.** The usefulness and satisfaction scores for the LDW system (audible to LDW and Both groups)

FCW and LDW systems are considered as both useful and satisfactory when experienced as isolated systems. When experienced in parallel, they are both rated as useful in terms of traffic safety but unsatisfactory. This could be simply, because the two parallel systems produced a rather noisy environment, causing a lot of irritation to drivers.

## 4 Discussion

Although the number of participants per group was small, the total number of trips analysed per group was 90. Keeping in mind the possible inter-personal differences among participants in each group, results from this study indicate that there is a difference regarding the effects on driving behaviour and acceptance of the two systems that were tested, when these systems are isolated or are functioning in parallel but independently of each other.

When the FCW and the LDW systems were operating isolated, there was an improvement of longitudinal and lateral behaviour respectively. Participants in the FCW group were trying to minimize system warnings due to close-following, as shown by the lower number of warnings, and were driving less time at short headways (<1s) than the other groups. This effect however did not last in time, as the percentage of time of driving at short headways (<1s) during the last five trips was higher than in the first trips, possibly due to drivers' personality and familiarization with the system. On the other hand, the total number of lane changes in this group was not different from the other groups, implying that the less time spent driving at short headways was not due to more frequent lane-changing. This suggests that the isolated FCW system had certainly a positive effect on longitudinal behaviour without inducing potential unwanted driving behaviour changes, e.g. increased number of lane changes in order to avoid FCW activation. A negative side-effect in this group was that the standard deviation of lane position was higher than in all other groups, possibly due to their concentration on longitudinal behaviour. The isolated FCW system was rated by them as useful and satisfactory.

Participants in the LDW group showed better lane keeping performance from the other groups, as the lower standard deviation of lane position and lower number of LDW warnings indicate, and they were using more often the direction lights during lane changes. These behavioural changes remained unaffected through trips, possibly due to drivers' personality. The number of FCW activations in the LDW group was less than in the reference group, possibly due to their more conservative driving style compared to the rest groups. These participants also rated the isolated LDW system as useful and satisfactory.

In the Both group in contrast, there was essentially no positive effect either in respect to longitudinal behaviour or in respect to lateral behaviour, in terms of number of warnings, driving at short headways and lane keeping performance. It seems like participants in the Both group paid no attention to the provided warnings. Their lane keeping performance was similar to the reference group. They drove at short distances more often than the reference group, possibly due to their driving style. Participants in this group rated both systems running in parallel as useful but not satisfactory.

Considering, the double number of warnings that participants in the Both group were receiving compared to the FCW and the LDW groups, and the resulting noisy environment that participants had to drive in, it was inexplicable why they did nothing in order to minimise the warnings. To answer this question, a follow-up telephone interview was conducted. From the answers to these interviews, it was found that trying to cope with both systems, generated a lot of frustration to participants, because the systems excessively delimitated their latitude of control compared to their usual driving style. Due to this frustration, several participants stated that they tried to pay attention to at least one of the two systems, but they soon abandoned this strategy as it was not effective, since the two types of warnings were not relevant to each other and were provided in different means, which created even more irritation and confusion to them.

These findings highlight the need for integration of the interfaces of in-vehicle systems. Several current and previous research efforts have been trying to design and develop integrated interfaces for in-vehicle systems. The key issues for an integrated interface could include the implementation of multimodal interface elements used by different systems, for example head-up displays, speech input/output, seats vibrators, haptic input devices, directional sound output, the prioritisation of warnings from multiple systems and scheduling of warnings according to the assigned priority level, thus avoiding conflicts between systems and the possibility for interface adaptivity according to the environmental scenario and the specific driver's state and preferences, taking always into consideration possible impact on driver's workload.

Further to this, it should be mentioned that the development of support systems has until now been based on a decomposition of the driving task and focuses on specific subtasks only. The most important outcome of our study is that such an approach imposes excessive delimitations to the driver, thus the real need is not to integrate all distinct systems, but to develop one unique system, that considers the entire driving task.

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