Designing ADAS: What kind of analysis is needed?

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ABSTRACT

The paper focuses on the effectiveness of the warnings provided by the advanced driver assistance systems (ADAS) in driving performance. It is suggested that ineffectiveness of such systems, both in terms of traffic safety and drivers' acceptance, is related to the violation of the cybernetics law of requisite variety between the controller and the system to be controlled. According to this law effective control is only possible if the variety of a controller matches to the variety of the outcomes (of the system) to be controlled. Therefore, a direction for improving the effectiveness of ADAS, providing drivers with appropriate and timely warnings, is to increase their variety both at the level of drivers' intentions and the situation at hand. The feasibility of such an approach is supported by the findings of two on-road experiments. Finally, the kind of analysis needed for designing ADAS that meet the requirement of requisite variety is discussed.

Keywords

ADAS design, law of requisite variety, driver modeling, close following, driver performance analysis

INTRODUCTION

Development of specific (task-oriented) driving support systems, the "so-called" *advanced driver assistance systems* (ADAS), is associated with a particular view of automobile driving as the sum of individual tasks. Following a reductionist approach, driving is analyzed into several individual sub-tasks (e.g. lane keeping, car-following, regulation of speed, etc.), and accordingly, driver behavior performance on each sub-task is studied separately and in isolation to the others. The main assumption behind this approach is that, studying each task separately, makes feasible the identification of the critical information that a driver uses when performing a particular task. Moreover, it helps the analyst to identify the critical information processing stages that could be benefit from ADASs, in terms of drivers' effort and error-performance (Villame and Theureau, 2001; Cacciabue and Hollnagel, 2005).

However, such an approach acknowledges neither the *variability of sources of information* that drivers use in real traffic conditions, nor the *variability of courses of action* that a driver is possible to undertake in order to overcome a critical situation. Consider, for example, the driving task of car following. Adopting a reductionist approach, car following task is simplified into a task of regulating a "target" following distance from the vehicle ahead. The primary information source that drivers use for making necessary adjustments, is the visual properties of the approached object (Lee, 1976). However, car following models based on naturalistic studies, show that during the transition from a free vehicle to a car following condition there are several intermediate stages (Ranney, 1999; Vogel, 2002). At each stage, a driver's decision to be involved in a car following condition as well as how close to follow the vehicle ahead is affected by different factors (e.g. traffic flow, vehicle speed, environmental/ individual factors, etc). In essence, each factor enhances a driver to achieve a better harmonization with the rest traffic at the various stages. That is to say, the core of the regulating actions undertaken by a driver is not to maintain a "target" following distance from a vehicle ahead, but rather to maintain a vehicle "safety envelope" from the surrounding traffic (Papakostopoulos and Marmaras, 2008).

Furthermore, by simplifying car following task as a regulating task of a "target" following distance from the vehicle ahead, the possible variety of drivers' courses of action is confounded into a minimum set of driver behavioral reactions: either to keep up following or to initiate braking. However, everyday experience shows us that braking is just one possible behavioral reaction of a driver. Thus, under a given set of traffic conditions an evasive maneuver might be more appropriate, in terms of traffic safety, instead of braking (e.g. the vehicle ahead brakes abruptly and at the same time the vehicle behind the ego-vehicle is close enough).

All the above suggest that developing an ADAS for assisting a driver in performing a particular task (e.g. car following) on a basis of single-rule (e.g. maintaining of a "target" following distance), may be insufficient to match with drivers' needs and intentions under a given set of traffic conditions. This, in turn, results to the provision of inappropriate warnings, causing drivers' annoyance and leading them to ignore a warning, even when it is necessary.

THE INEFFECTIVENESS OF REDUCTIONISM IN ADAS DESIGN AND THE "LAW OF REQUISITE VARIETY"

Taking a systemic view, we can say that the main cause of ineffectiveness of ADASs designed adopting a reductionist approach, is the violation of the "Law of Requisite Variety" (Ashby, 1956). This law, which was formulated in cybernetics, states that effective control in not possible if the controller has less variety than the system to be controlled. In the case of ADAS design, the law of requisite variety has been violated twice.

The first violation is at the level of modeling the driver as a controller of the situation at hand. As it was mentioned above, due to the reductionism in modeling driving behavior, the variety of driver performance is limited, compared to the observed one in real situations. This further suggests that important aspects of driver performance (e.g. drivers' strategies for controlling the situation at hand) might be hidden, whereas, important types of information that a driver needs (e.g. integrated information about vehicle-road system) might not be considered.

The second violation is at the level of modeling the ADAS as a controller of the outcome of driver performance in a given set of traffic conditions. As it comes out from the above, the variety of driver performance assumed by an ADAS is inevitably limited. Furthermore, the source of information that an ADAS use (e.g. time headway or time-to-collision criterion) in order to evaluate the outcome of driver behavior is also limited. Putting it in terms of the law of requisite variety, there is an oxymoron as it is expected that a controller with less variety (i.e. an ADAS) will effectively control a system with high variety (i.e. the outcome of driver behavior at a plethora of traffic situations).

Therefore, a possible direction for improving the effectiveness of the warnings provided by an ADAS is to increase the variety of the ADAS (as a controller) in order to meet the requirement of a requisite variety. However, a critical question is how much variety is needed. As Hollnagel and Woods (2005) argue, to account for actual performance there is clearly no reason to have more variety in the model than needed, if the predicted performance matches the actual performance sufficiently well.

To support the above arguments, in the present paper the results of two on-road experimental studies are presented. The first one deals with the observed variety of driver performance when using two different ADASs in a realistic setting. The second study deals with the drivers' controlling actions in a close following situation and the real-time driver behavior parameters that are related with. It is maintained that in order to achieve sufficient variety of ADASs, it is necessary to extend our analysis of driver behavior performance, before adding more technology for driver monitoring.

STUDY I: LONG-TERM EFFECTS OF ADAS' WARNINGS IN DRIVER BEHAVIOUR

The study to be reported here was conducted within the **AIDE** (Adaptive Integrated Driver-vehicle interfacE) Integrated Project, funded by European Union, and it has been described in detail elsewhere (Portouli et al., 2006).

The objective of this study was to determine the possible long-term behavioral changes associated with the use of a stand-alone ADAS or a combination of two ADAS, namely a Forward Collision Warning (FCW) and a Lane Departure Warning (LDW). In the following section a brief description of the on-road experiment is outlined putting emphasis on the effectiveness of the warnings provided in driving performance, when the two ADAS used as stand-alone.

Study Design

A one-way, unrelated samples experimental design was used. The main variable was the number of ADAS warnings provided to participants, with three levels (warnings provided only by the FCW system; warnings provided only by the LDW system; warnings provided from both FCW and LDW systems), whereas the control group did not receive warnings. The primary dependent variable was the number of the actual or the potential warnings that participants would receive. Other depended variables were: traveling speed, number of imminent frontal collision warnings, percentage of time driving at short time headway (TH < 1s), standard deviation of lateral position, number of lane changes, and number of lane changes with use of direction lights.

In total 24 participants (14 males – 10 females) ranged in age from 21 to 50, with a mean age of 32.9 years (SD = 7.6) took part in this study. All participants hold a driving license for at least 3 years (mean = 12,4; SD = 6,9), whereas, theirs annual mileage was ranged from 5000 to 100000 km (mean = 27583,3; SD = 23564,7).

The experiment was conducted on a standard route in Thessaloniki, Greece, consisted of a highway (total route distance 79 km), using an experimental vehicle based on a Lancia Thesis 2.4 Emblema. The experimental vehicle was equipped with a front obstacle detection radar, providing information about front obstacles (distance, relative speed), a lane recognition camera, providing information about vehicle position relevant to the lane, and an electronic unit, collecting information from the vehicle electronic system (i.e. acceleration pedal position, brake cylinder pressure, vehicle longitudinal speed and acceleration, yaw rate, steering wheel angle, lights status etc.) and exporting them to the central PC for processing.

The duration of the study was 15 weeks. Along this period, the 24 participants, equally allocated into four experimental conditions, were asked to drive the experimental vehicle for one hour per week along the standard route. To eliminate the effect of confounding variables, each participant drove the vehicle at the same day and time each week, so that variations in traffic conditions were kept as minimum as possible among consecutive rides. Additionally, participants in four conditions were matched in terms of age and driving experience.

Main Findings

A main finding of this study was that the long-term behavior changes associated with the use of the two ADAS tested, were quite dissimilar when these support systems are used as stand alone or are functioning in parallel but independently of each other.

Specifically, when the two ADAS were functioning concurrently, there was no performance improvement but rather performance deterioration both in terms of car following distance and lateral position in relation to the lane. Follow-up interviews, revealed that participants purposefully ignored the warnings provided from both FCW and LDW systems, because the safety margins defined from both support systems, made driving too restricted to be respected during 1h journey.

When the two systems were used as stand alone, a statistical significant difference was found in drivers' performance when using the FCW or the LDW system, with regard to the extent at which changes in car following distance and lateral position, respectively, remained stable over time.

Specifically, during the first weeks participants who drove with the FCW system were affected by the system's warnings, spending less time driving at short time headway (TH < 1 s). Instead, as the time passed, they were less affected by the system's warnings, spending much more time driving at short time headway. This effect was statistically significant. On the other hand, participants who drove with the LDW system proved to be affected by the system's warnings all the 15 weeks of the study. In fact, these participants compared to the other groups showed better performance, in terms of standard deviation of vehicle lateral position and frequency of use of direction lights during lane changes

Discussion

A thorough consideration of the functional characteristics of the two ADAS tested, namely the FCW and the LDW system, revealed that a key-difference lays into their ability to vary the warning emission according to the driver's intention. Specifically, in the case of the FCW system, the criterion for a warning emission is based exclusively on time headway measures, independently of the situation (e.g. driver's intention to overtake). In contrast, in the case of the LDW system, two criteria should be fulfilled for a warning emission: (i) the vehicle exceeds upon the lane markers and (ii) the direction lights are not activated. In this case, apart from the objective measure of vehicle lateral position in relation to the lane, the additional criterion of the status of the direction lights, provides an input to the LDW system for identifying instances of involuntary lane exceedness (e.g. lane drifting) and voluntary ones (e.g. lane change, overtaking).

Based on the above findings it comes out that the increased variety of the LDW system provided by a simple but sufficient criterion, contributed to its higher effectiveness. Consequently, a question of interest is whether it is possible to identify sufficient criteria for increasing the variety of the FCW system. This issue is examined in the following study.

STUDY II: LONGITUDINAL BEHAVIOR DURING CLOSE-FOLLOWING

The objective of this study was to investigate the drivers' strategies for controlling vehicle course in close-following situations. Observational studies of car following behavior show that drivers do not comply with the recommended two-second rule for safe following distance (Michael, Leeming and Dwyer, 2000; Taieb-Maimon & Shinar, 2001; Brackstone and McDonald, 2007). In this study we aimed to analyze driver performance during close following in an attempt to determine the possible parameters that affect a driver's decision to maintain a close following distance before initiate a braking action. The motive behind it is that these parameters could be used as signs by a FCW system for increasing its variety.

Study Design

A one-way, related samples experimental design was used. The main variable was the traveling speed of the vehicle ahead with two levels (40 and 60km/h). The primary dependent variable was the time at which the following driver initiates a braking action in relation to time headway between the two vehicles. Other depended variables were: longitudinal speed, lateral position, acceleration, steering wheel angle and brake cylinder pressure of the following vehicle.

The experiment was conducted along a straight course (1.2 km) of a secondary road in Thessaloniki, Greece, using the same experimental vehicle as described in study I. The same driver drove the vehicle ahead (Renault Laguna 1.6) throughout the experiment.

In total, 10 participants (8 males – 2 females) ranged in age from 19 to 44, with a mean age of 28.5 years (SD = 6.8) took part in the experiment. Except one participant, all other participants hold a driving license for at least 5 years (mean = 10,3; SD = 6,4) and their annual mileage was ranged from 3000 to 60000 km (mean = 21000; SD = 14944,3).

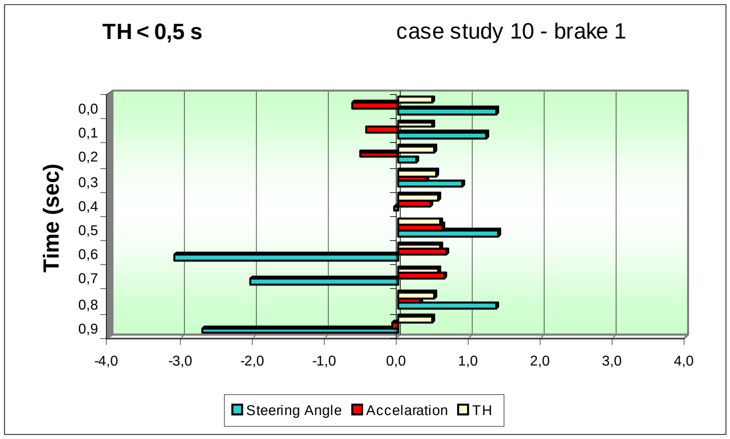
During the experiment, participants were asked to follow the vehicle ahead as close as possible, knowing that the driver of the vehicle ahead would perform sudden brakes. On the other hand, the instruction to the driver of the vehicle ahead was to maintain a constant speed (40 or 60 km/h) and to perform sudden brakes at random moments. In total, all participants were forced to a braking action four times.

Results

A main finding of this study is that during a close-following situation, a driver's decision to initiate a braking action is not exclusively related to the changes of the time headway between the two vehicles. Thus, in an attempt to understand the possible factors that might influence a driver's decision to initiate a braking action, during close following, we decided to extend the typical "unit" of analysis of a close following instance. That is to say, instead of focusing on the last second before the braking action, we analyzed the drivers' performance during the last 10 sec before braking, considering the following driver behavior parameters: time headway, acceleration and steering wheel angle. Two typical examples of this analysis are shown in Figure 1.

As it can be seen in these figures, during the last 10 sec of a close following, time headway values remain quasi-constant. We assume that this regularity is the result of two complementary controlling actions that a driver is performing. The first one is adjustments of the field of travel longitudinally through recursive alternations in gas-pedal pressure, which lead to changes in vehicle acceleration. The second controlling action is adjustments of the field of travel laterally through recursive changes in steering wheel angle.

Analysis shows that the two complementary controlling actions (i.e. vehicle acceleration and steering wheel angle) are correlated in the following way: at each second of a close following situation, the smaller the difference of acceleration (relative to the previous second) the higher the change of the steering wheel angle.



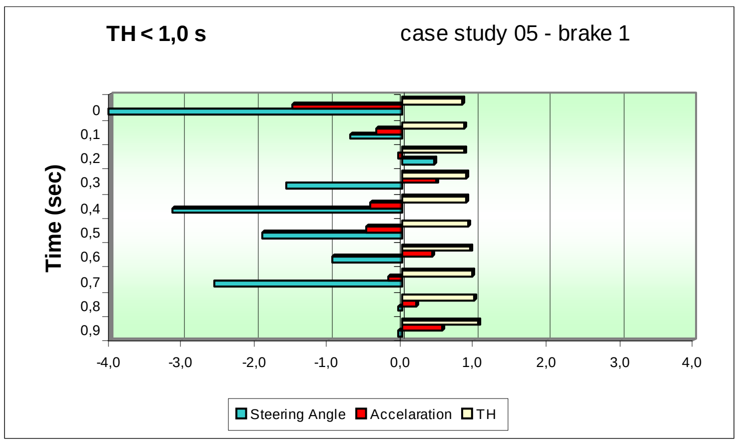


Figure 1: Two characteristic example of changes in time headway, acceleration and steering wheel angle during close following, of two participants.

Discussion

A thorough consideration of driving behavior during close following reveals that the two controlling actions that were observed in this study are complementary to each other. That is to say, as a driver approaches a lead vehicle it is possible either to decelerate through a gas-pedal release or to move laterally for both to decrease the relative speed and to be prepared to make an evasive maneuver. This may explain the interplay between the two driver behavior parameters that was observed, during the last 10 seconds. This also suggests that a driver's decision to initiate a braking action is related to the perceived ineffectiveness of the two controlling actions to avoid a rear-end collision.

The findings of this study seem promising towards the direction to take advantage of the real-time driver behavior parameters in order to identify whether a driver is aware of being involved in a critical traffic situation or not. The point of interest here is that when a driver is close following a vehicle ahead and takes controlling actions –such as changes in vehicle acceleration and changes of steering wheel angle– indicates that the driver is purposefully tailgating. Consequently, in this case a warning emission of a FCW system seems to be useless. Therefore, taking advantage of the real-time driver behavior parameters for determining whether a driver is aware of being involved in a critical situation could be used as an additional criterion for increasing the variety of the FCW system.

CONCLUSIONS

New technological systems for assisting a driver to perform one or more driving tasks, generically named as ADASs, raise important questions both in terms of their effectiveness and consequences in driver behavior performance (Saad, 2006). In this paper, the issue of the effectiveness of ADASs' warnings in driver performance was encountered.

Taking a systemic approach, we support that a core cause of the ineffectiveness of ADASs' warnings is that they assume a limited variety of driver performance, compared to the observed one. As a direct consequence, and considering the "law of requisite variety", it derives that in order to improve the effectiveness of an ADAS –as a controller of the outcome of driver behavior–, it is needed to increase its variety. This implies that the criteria for the emission of ADASs' warnings should be more sensitive both at the level of drivers' intentions and the situation at hand. In other words, the ADASs' design criteria should be context-depended.

We suggest that the above objective is not simply a technological challenge, since the limited variety of ADAS is also due to the usually adopted reductionist and context independent driver models upon which they are developed. Consequently, a shift to the research paradigm used for analyzing the driver's behavior performance is needed. In effect, we need a kind of analysis that captures the diverse driver's behavior performance in relation to the driver's intentions and the traffic context.

As it was seen from the first on-road experiment, a key-factor for the effectiveness of an ADAS on driver performance is its ability to vary the warning emission according to the driver's intentions, which is indicated through some implicit "signs" (e.g. the status of the direction lights as an input to the LDW system for identifying a voluntary vs. involuntary lane exceedness). Results from the second on-road experiment provide evidence that by analyzing what a driver does in real traffic situations, it is possible to identify "signs" that can be used as inputs to an ADAS for determining whether a driver is aware of being involved in a critical traffic situation, and thus, whether a warning emission would be useful.

Cognitive work analysis aiming to identify driver behavior parameters that are indicative to describe the drivers' intentions in various traffic situations, seems to be a promising tool of analysis and development of context dependent driver's models. Based on these models ADASs with increased variety could be designed, ensuring thus higher effectiveness.

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