How ADAS alert resources match the Driver-Vehicle-Environment system model: an analysis of co-design data

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Abstract. *Driver behavior and interaction with Advanced Driver Assistance Systems (ADAS) play a vital role in realizing their full safety potential. In light of this, in-depth studies on the user experience (UX) of ADAS are of paramount importance to achieve the expected improvements in road safety. The Driver-Vehicle-Environment (DVE) system model integrates human perspectives with vehicle dynamics and environmental factors to provide insights into the interactions within this system. In this paper, we analyze the elements of ADAS alert prototypes proposed in co-design sessions. Our main goal was to check whether these proposals considered important elements of the DVE model. As a contribution, we pointed out elements that could be further explored in co-design sessions of ADAS.*

1. Introduction

Advanced driver assistance systems (ADAS) denote technologies that automate, enhance, and optimize vehicle systems to achieve safer and more efficient driving [Antony and Whenish 2021]. This includes features that provide warnings and/or temporary intervention, such as forward collision warning systems [SAE International 2021]. ADAS have the potential to significantly improve road safety by preventing accidents and minimizing damage [Cicchino 2018]. The assessment presented by [Kühn and Hannawald 2016] reveals scenarios in which the use of different combined ADAS resources has the potential to prevent car accidents in more than 40%. Although ADAS has impressive potential to enhance safety, its effective use at lower levels of automation relies on human response, understanding, and adoption [SAE International 2021] [Gasser et al. 2016].

In this paper, we conducted an analysis of the ADAS information notification proposals to assess whether the proposals include the elements of a driving system model that consider three elements, i.e., drivers, ADAS, and environment. The proposed notifications were produced in a co-design workshop, and the data was collected and analyzed by [Lisboa et al. 2023] in a previous study [1]. The results of our analysis showed that the notification proposals covered different elements of the system model; however, they did not explore explicitly the drivers' needs.

2. Driver-Vehicle-Environment System Model

Understanding the driver's experience goes beyond their interactions with ADAS [Orlovska et al. 2020] [Cacciabue and Saad 2008]. It relies on human information processing (HIP) systems, which include *information intake*, *information processing*, and *information output* [Abendroth and Bruder 2016]. *Information intake*, i.e., perception, involves recognizing

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[1] The previous study paper also makes this data available.

stimuli (i.e., visual, auditory, haptic, or vestibular). *Information processing*, i.e., cognition, involves decision-making based on the comparison of sensory impressions with learned structures of thought and judgment. Finally, *information output*, i.e., the response is the motor action [Abendroth and Bruder 2016]. HIP can be assumed by different models to be: (i) strictly sequential; (ii) performed simultaneously while sharing limited resources; or (iii) a combination of sequence and resource models, in which available resources are limited and allocated based on the application of attention [Abendroth and Bruder 2016]. In this paper, we adopt the Driver-Vehicle-Environment (DVE) model [Abendroth and Bruder 2016], which aligns with the model (iii) above, to carry out our analysis based on HIP and to provide a model that integrates human perspectives with vehicle dynamics and environmental factors to provide insights into the interactions within the driving system [Orlovska et al. 2020].

Figure 1 presents a simplified version of the DVM model that includes: the *driver (a)*, as a human with capabilities, skills, and personality; the *vehicle (b)*, with displays, dynamics, input devices, and ADAS; and the *environment (c)*, which includes other vehicles and road users, weather, visibility, and the route. The main element is the *driver (a)*, whose characteristics (e.g., sex, age, and personality) influence risk perception and behavior, capacities (i.e., cognitive, sensory, and motor abilities) influence information capturing and processing, and driving skills (i.e., experience, style, and type) that impact risk recognition and vehicle control. The demands on the driver are influenced by the *environment (c)* factors like weather, visibility, the route, and the behavior of other road users, as well as inputs from the *vehicle (b)* such as ADAS, displayed information, and vehicle dynamics.

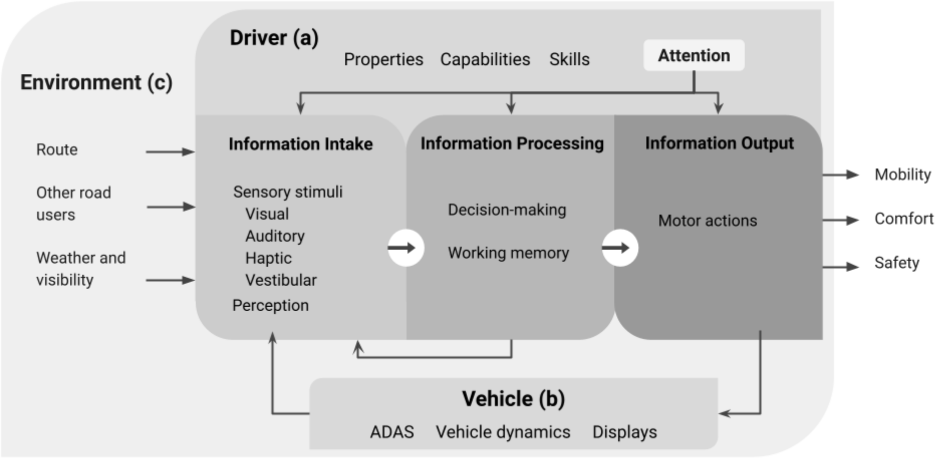

Figure 1. Simplified version of the Driver-Vehicle-Environment model adapted from [Abendroth and Bruder 2016].

The demands of driving introduce some challenges to human performance capacity. Drivers need to identify and evaluate situation-dependent information about the vehicle and its environment to make appropriate decisions on actions [Abendroth and Bruder 2016]. Although vehicle manipulation (output) is mainly automatic, complex or infrequent demands require more attention, potentially leading to excessive workload and high-stress levels [Li et al. 2020] [Weller and Schlag 2016] [Abendroth and Bruder 2016]. The workload must remain manageable for the driver to use the system without losing focus on the primary task of driving [Li et al. 2020]. Therefore, the user experience (UX) of ADAS should be designed to consider the stimuli and frequency of the demands presented to the driver, the ease of usage, and the correct understanding of the driver's and vehicle's roles [Li et al. 2020] [Frison et al. 2019] [Birrell et al. 2014] [Abendroth and Bruder 2016].

3. Data analysis and Main results

As mentioned above, our analysis was carried out based on the data collected by [Lisboa et al. 2023] in a co-design workshop to conceive a blind spot alert system. The co-design workshop had nine participants divided into three groups (A, B, and C); the participants were of different professional backgrounds (psychologists, engineers, app drivers); had a varied driving experience, and represented different age groups (18-30, 31-40, 40+), with the majority being male. The participants produced four low-fidelity (lo-fi) paper prototypes[2] with cards representing different types of notification (visual, haptic, and auditory) placed over images of vehicle perspectives. The notification aimed to inform drivers about the presence of a motorcycle in the vehicle's blind spot[3].

We examined the first level of results obtained by [Lisboa et al. 2023][4]. Each solution included the group (A, B, C, or all combined) that designed it, the location in the car where the notification should happen, the notification type (visual, auditory, haptic), an explanation of the notification in action, and weather/how the notification could be used in redundancy. The results of our analysis can be seen in Table 1. In the lines, we see the reference for each participant's groups (A, B, C) and the consolidated version of the designs made by the three groups combined, while the columns represent the elements of the simplified DVE model (see Figure 1). In our analysis (see model in Figure 1), *environment* data were obtained from the notification description; *vehicle* data from the notification location in the vehicle; *information intake* from the notification type and redundancy usage; *information processing* from the notification description and redundancy usage; and *information output* from the notification description.

Our results showed that, in summary, all three groups proposed using the main *information intake* types (i.e., visual, auditory, haptic) and their redundancy, where multiple types of notification are provided simultaneously to improve perception and convey urgency. *Information processing* was addressed by all groups, focusing on the association of symbols and inputs with information. Additionally, some groups addressed under-stimulation (haptic alerts to get attention), attention allocation (radio volume reduction during critical moments), and spatial orientation (surround sound, one-sided haptic alerts). *Information output* was less explored, with only group B proposing to force the driver to turn on a specific scenario. The literature suggests that participants could be advised to consider the desired response to notifications. For instance, to notify in a timely manner that allows the driver's motor action [Weller and Schlag 2016]. *Environment* factors were considered by all groups, they were the side from which the motorcycle was approaching and the current distance between the motorcycle and the vehicle. However, context variables that can influence driver attention, such as weather and visibility, were not considered as suggested by [Orlovska et al. 2020]. The *vehicle* was well explored, with existing and new features proposed. The *driver* element carries the potential to inspire solutions that address the driver's individual needs, however, there were no mentions of addressing the personas or their limitations in specific features. Upon inquiry, the authors disclosed that there were discussions about the driver, but these were not reflected in the recorded design data.

Additionally, this analysis raised attention to non-explicit elements of the model. Ac-

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[2] Prototype images are available at: `https://bit.ly/3WQOYQ8`

[3] Comprehensive details are available in [Lisboa et al. 2023].

[4] Data analyzed is available at: `https://encurtador.com.br/8hRrY`

Table 1. Solution proposals data addressed by group and categorized by element of simplified DVE model (see Figure 1)

			Information			
Group	**Environment**	**Driver**	**Intake**	**Processing**	**Output**	**Vehicle**
A	side from which the motorcycle is approaching; the current distance between the motorcycle and the vehicle;	-	visual; auditory; haptic; redundancy;	association;	-	internal rear-view mirror; instrument cluster display; steering wheel; vehicle's panel; external rear-view mirrors;
B	side from which the motorcycle is approaching; the current distance between the motorcycle and the vehicle;	-	visual; auditory; haptic; redundancy;	association; under stimulation (attention getter alert); attention allocation (radio volume down); spatial orientation (surround sound);	output expectation (turn signal);	external rear-view mirrors; strip light on the driver's door; instrument cluster display; steering wheel; driver's seat; driver's cabin; driver's door; multimedia panel;
C	side from which the motorcycle is approaching; the current distance between the motorcycle and the vehicle;	-	visual; auditory; haptic; redundancy;	association; frequency of demands; spatial orientation (surround sound);	-	external rear-view mirrors; steering wheel; car's cabin;
All	side from which the motorcycle is approaching; the current distance between the motorcycle and the vehicle;	-	visual; auditory; haptic; redundancy;	association; spatial orientation (surround sound)	-	external rear-view mirror on the driver's side; steering wheel; car's cabin; instrument cluster display;

cording to [Weller and Schlag 2016], [Li et al. 2020], and [Birrell et al. 2014], frequency of demands, workload, and stress factors can reduce the focus on the main task of driving. However, among these factors, only the frequency of demands was addressed, and this was done solely by group C.

4. Conclusion

This paper has the contribution of exploring the solutions of ADAS notifications with a driving system model. Our results showed that the solutions resulted from the ADAS co-design workshop conducted by [Lisboa et al. 2023] covered most of the elements of the Driver-Vehicle-Environment model. Nonetheless, the notification solutions could benefit from an explanation of a few elements and their importance to participants beforehand. Frequency of demands and context variables like weather and visibility can influence driver attention and were not considered. We suggest that they could be further explored, as they are the main stress factors and can directly contribute to ADAS adoption. Besides, the driver's individual needs were little explored. In the results, there were no mentions of addressing the personas offered to the groups or their limitations in specific features. We recommend that participants of a co-design session be advised to be explicit about considerations concerning the drivers' needs. To advance our study, we intend to explore driver behavior models and other co-design results that will be conducted in the future.

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