Road Safety: Human Factors Aspects of Intelligent Vehicle Technologies

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Abstract. The design of road-vehicle systems has a crucial impact on the driver's user experience. A post-market trial-and-error approach of the product is not acceptable, as the cost of failure may be fatal. Therefore, to design a suitable system in the automotive context that supports the driver during their journey in an unobtrusive way, a thorough survey of human factors is essential. This article elucidates the broad issues involved in the interaction of road users with intelligent vehicle technologies and summaries of previous work, detailing interaction-design concepts and metrics while focusing on road safety.

Keywords: Human Factors, Driving Task, User Interfaces, Interaction, Intelligent Vehicles

1 Introduction

The International Ergonomics Association [11] defines ergonomics or human factors (HF) as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance", a definition that has also been adopted by the Human Factors and Ergonomics Society [12]. According to the International Standardization Organization (ISO) standard 9241-210, user experience (UX) stands for an individual's perception and responses resulting from the use of a product, system, or service [27]. The user's emotions, beliefs, preferences, physical and psychological responses, behaviors and accomplishments that occur before, during and after use all figure into the overall user experience. Relying on these definitions and the holistic approach depicted in Figure 1, HF aims at meeting user needs generating products for a positive UX that are a joy to own and to use [44]. To this end it aligns knowledge and methods from multiple disciplines (i.e. software engineering, psychology, statisticians, designers, etc.) based on empirical data collection and evaluation. For example, graphical user interfaces (GUI) for pedestrian navigation and routing systems might enhance road safety and provide an optimal UX if they are developed in a user friendly manner. They can include aspects that connote a positive feeling

The final publication is available at Springer via https://doi.org/10.1007/978-3-030-02907-4_16

and a pleasurable experience, such as a shaded path in hot and sunny summer days [48].

According to the ISO 9241-210:2010 "Ergonomics of human-system interaction - Human-centered design for interactive systems" user, system (consisting of task to be performed and product interacted with) and context of use affect UX [27]. Figure 2 shows how vehicular content as context of use can be arranged into this scheme, where the system is traffic in which the primary driving task (and also sometimes secondary and tertiary) takes place, the vehicle is the product interacted with and the driver is the user.

70% to 80% of new product development failure is due to a lack of understanding of user needs rather than a lack of advanced technology [24]. User centered design (UCD) entails consideration of the user's requirements within the design phase of a service or good being produced. As a consequence, the intended context of use will be reflected in the representation of the system's mental model of how such system should work [18]. Therefore, user mental models need to be considered to effectively design systems that reflect user expectations. This is particularly important for systems that are critical to decision making processes in cognitively demanding scenarios [42].

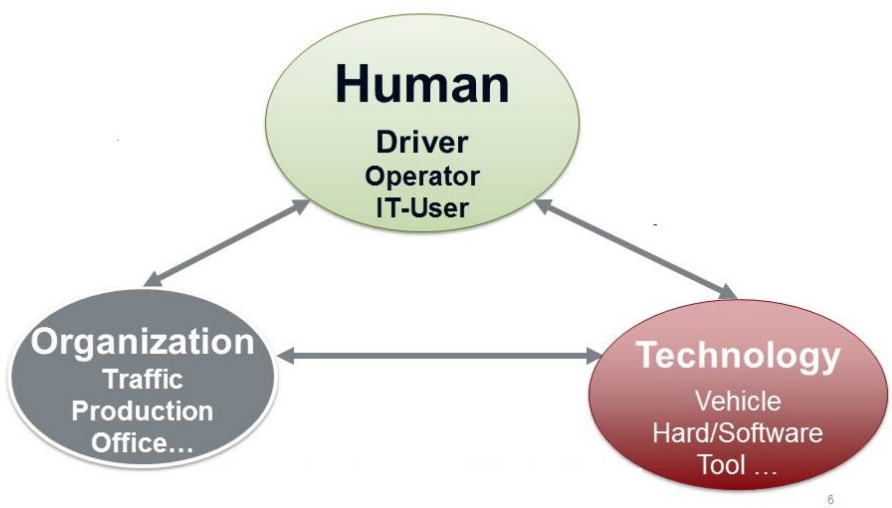

Fig. 1. Holistic approach to the scientific discipline of human factors (adapted from [13]).

The overall diffusion of the application of digital technologies in homes, buildings and cities presents the possibility of designing systems whose functioning is based on intelligent technologies that simultaneously reside in multiple, interconnected applications [37]. As a consequence, the development of intelligent

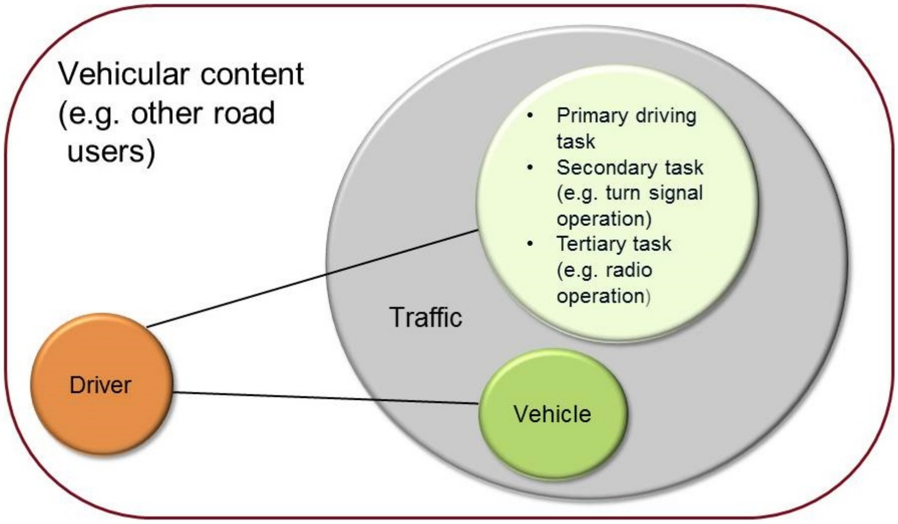

Fig. 2. Representation for a vehicular content of the elements that affect UX according to the ISO 9241-210:2010.

road-vehicle systems such as advanced driving assistance systems (ADAS) is rapidly increasing [17, 35]. Many of these systems rely on sensors that collect certain data, for example to identify the distance to the preceding vehicle or the information shown on traffic signs. Vehicle-to-Vehicle (V2V) communication opens up the possibility of designing cooperative ADAS (co-ADAS) that use data collected by sensors located in other vehicles [38, 21]. Their purpose is to support the driver in the driving task, for example by extending the driver's field-of-view so they can be warned beforehand of a wide range of threats. However, these vehicular systems do not always enhance driving safety when perceiving this information leads to visual distraction or taking one's eyes off the road. This diversion could instigate a loss of vehicle control if the eyes-off-road time exceeds 2 seconds, the recommended limit for glance away from the roadway time by the National Highway Traffic Safety Administration (NHTSA) [14]. This is reflected in the number of road accidents reported by the NHTSA: in 2011 alone, 10% of fatal crashes and 17% of crashes resulting in injury in the US were reported as distraction-affected [36], meaning that 390.331 people were killed or injured in crashes involving a distracted driver. Over 17% of these distractions were influenced by mobile phone use or the manipulation of other systems in the car.

Moreover, due to the fact that drivers have restricted capabilities for processing multiple sources of information, attentional demand can cause driver overload of attentional capacity when their processing capabilities are already near the upper threshold (e.g., when the traffic is demanding). Therefore road-vehicle systems intended to increase the driver's awareness of the surrounding environment need to be designed to ensure high usability, acceptance, efficiency and understanding on the part of the driver.

This article elucidates the broad issues involved in the interaction of road users with intelligent vehicle technologies, including summaries of previous work, and will focus on the information flow to which we are exposed while driving. It will include input and output modalities and detail the visual demand required in the vehicle. It will finish with a close look at cooperative systems and automation.

2 Vehicular Interaction

2.1 Information Flow

The overall driving task consists of operating a vehicle by performing many smaller, uncomplicated tasks concurrently. Complexity of vehicular interaction increases with the number of vehicles in traffic and higher traveling speed, as these factors make it more difficult to maintain awareness of the surrounding traffic environment and react to unexpected events and driving maneuvers from other road users. Some of the tasks related to driving are as follows:

- control of speed
- observance of the distance to the leading car
- steering
- traffic observation and action prediction
- navigation
- interaction with car controls
- awareness of the in-vehicle information output
- traffic signs and rules awareness

In addition, interaction in a vehicular environment can include lane shifts involving a combination of vehicle speeds and sizes, an ample spectrum of driving styles and a variety of illumination, weather and road conditions [53]. Furthermore, a transfer of information occurs during the driving process from driver to vehicle, driver to traffic environment and driver to co-driver or passengers and vice versa (Figure 3).

According to multiple resource theory, people are supposed to have a variety of resources (visual, auditory, cognitive, and psychomotor) that are dynamically allocated to tasks based on their characteristics [55]. If sources of information are augmented by the automobile industry by adopting technologies that can be found in other mobile environments, such as smart phones and tablets that stream personalized content into the car, the capacity of attentional resources or the total amount of information the human brain is capable of retaining at any particular moment [29] can be affected.

As people spend a considerable amount of time driving, the latest implemented vehicular technologies intend to improve the travel experience by increasing safety and comfort as well as by enhancing entertainment possibilities. Research related to the human processing capabilities particularly regarding

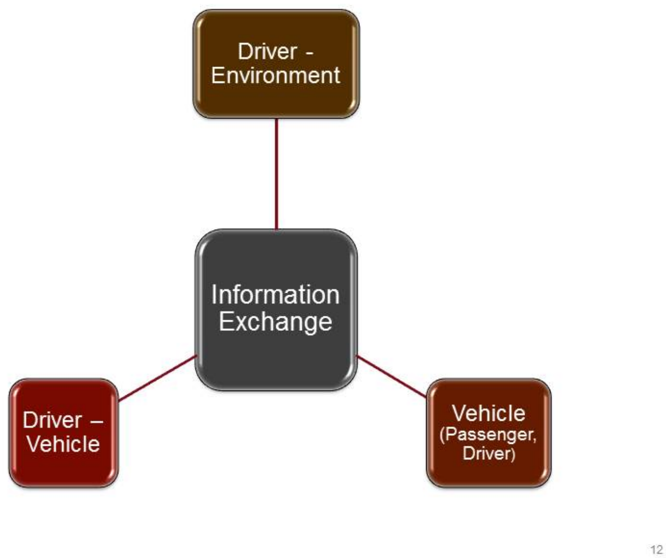

Fig. 3. Information flow in a vehicular context.

how much information the human being can process under driving conditions is therefore essential to ensure road safety.

The ISO is responsible for a vast number of standards which could be used either during the development of a particular human machine interface (HMI) or for its subsequent testing. The requirements, specifications, guidelines and characteristics compiled in Table 1 can be used consistently to ensure that a system is suitable for use in a vehicular context.

They focus on an in-vehicle presentation of information that improves the user experience and eases the learning process of road-vehicle systems. This was reflected in the results of several studies that examined the display modality and location in a central versus distributed display [30]. Additional works analyzed location preferences for driver information systems (DIS) and ADAS relative to the information they provided [39] and subsequently validated the results in a driving simulator [45].

2.2 Input Modalities

Today's cars have become more complex regarding driver interaction, due in part to a digital era that has changed people's habits and perception of content. An

Table 1. Most relevant standards for the design of in-vehicle interfaces

Targeted HMI System	Relevant Standards
Human centered design principles and activities for computer-based interactive systems.	ISO 9241-210:2010 “Ergonomics of human-system interaction - Human- design for interactive systems” [27]
Specifics for elliptical models in three dimensions to represent location of driver’s eyes and determine field of view.	ISO 4513:2010 “Road vehicles - Visibility - Method for establishment of “eyellipses” for drivers eye location” [5]
Warning Messages and Signals - to clearly perceive and differentiate alarms, warnings and information signals while taking into account different degrees of urgency and combining modalities of warnings.	ISO 11429:1996 “Ergonomics - System of auditory and visual danger and information signals” [1] ISO/TR 12204:2012 “Road Vehicles - Ergonomic aspects of transport information and control systems - Introduction to integrating safety-critical and time-critical warning signals” [6] ISO/TR 16352:2005 “Road vehicles - Ergonomic aspects of in-vehicle presentation for transport information and control systems - Warning systems” [3]
Drivers Visual Behavior - Assessment of impact of human-machine interaction.	ISO 15007-1:2014 ”Road vehicles - Measurement of driver visual behavior with respect to transport information and control systems - Part 1: Definitions and parameters” [7] ISO 15007-2:2014 ”Road vehicles - Measurement of driver visual behavior with respect to transport information and control systems - Part 2: Equipment and procedures” [8]
In-Vehicle Displays, e.g. image quality, legibility of characters, color recognition, etc. and procedures for determining the priority of on-board messages presented to drivers.	ISO 15008:2009 “Road vehicles - Ergonomic aspects of transport information and control systems - Specifications and compliance procedures for in-vehicle visual presentation” [4] ISO/TS 16951:2004 “Road Vehicles - Ergonomic aspects of transport information and control systems - Procedures for determining priority of on-board messages presented to drivers” [2]
Suitability of Transport Information and Control Systems (TICS) for Use While Driving.	ISO 17287:2003 “Road vehicles - Ergonomic aspects of transport information and control systems - Procedure for assessing suitability for use while driving” [28]

increase in novel interactions on mobile devices and a growing reliance on the provided content of developed applications has stimulated our perception and acceptance of interactive digital technology, thereby creating many opportunities for interacting with useful and attractive in-vehicle user interfaces devoted to safety, comfort and infotainment. As a consequence, input modalities in the form of mechanical parts of HMIs are increasingly being replaced by digital substitutes.

Interaction in the vehicle takes place while driving therefore affecting control of the vehicle, and the resulting driving performance while performing secondary and tertiary tasks can be measured by comparing individual performance with standard values that have been gathered as average from participants.

In this context, the selection of the most appropriate driving performance metrics depends on the objective of the experiment and the system to be tested. The following parameters are commonly used to monitor driving behavior [49]:

- speed-related parameters for measuring visual distraction while performing secondary tasks. For example, reduced speed is an indicator of road visual distraction that involves taking one's eyes off the road [25].
- lateral position parameters for measuring driving under cognitive load.
- parameters which describe headway performance changes measure visual or cognitive distraction.

Research on the best input modality for in-vehicle device interaction is being undertaken and investigating for example buttons and sensors in the steering wheel or the use of handwriting recognition. The ideal interaction should be eyes and hands free and one which causes no distraction. Natural language processing makes it possible to intuitively interact with a natural user interface through speech. Dialog systems based on spoken language, allow the interaction with computer-based applications through the use of voice [32]. A distraction from traffic as brief as powering on a car radio or answering a call on a mobile phone represents an increased risk of accident, therefore the potential of using dialog systems based on spoken language in road-vehicle applications is very large.

2.3 Display of Information

To design a suitable user interface in the automotive context the amount of information to display needs to be considered. As stated in [46] a large quantity of messages can be conveyed, expanding the range of possible display areas through non-conventional locations. Particularly the use of windshields as HMI could provide benefits for a low penetration rate of connected or automated vehicles, as they would provide an effective way to convey important safety-related information [43].

Figure 4 illustrates an approach in which visual data related to safety distance is provided to the rear vehicle in real-time, independently of the communication capabilities of the following vehicle and which relies on an asynchronous collaborative process [40].

Fig. 4. Windshield-conveyed message related to safety distance, independent of the communication capabilities of the trailing vehicle (adapted from [43]).

Regarding in-vehicle information location, a distance warning system based on vehicle-to-vehicle (V2V) communication would be able to additionally convey the time-gap between the connected vehicles, issuing a warning inside the following vehicle depending on an established threshold [33].

Regarding the preferences for in-vehicle location of information in the study by [41], 4 fairly homogeneous groups of functions were distributed in 4 different display locations, the locations proximity to the field of view of the driver increasing according to the urgency of the messages that they conveyed. An example of this principle being that drivers preferred having entertainment-related functions displayed outside their visual field, and social media and apps integration in a vehicular context were not considered essential to be displayed at all. Figure 5 shows a) an example of distribution of the vehicle functions in given displays [47] and b) the perceptual map with the relative positioning of all functions in the multidimensional scaling diagram [41].

3 Visual Demand in the Interaction with Road-Vehicle Systems

Driving distraction implies diversion of the driver's attention away from the road to focus on another activity instead [50]. Furthermore, not every demand loads attentional resources equally. Each task has its own demands on the processing capabilities of the driver. The environment exhibits different properties, such as static or dynamic and familiar or unfamiliar, and it represents varying degrees of visual complexity. As indicated in [45], multiple glances between in-vehicle

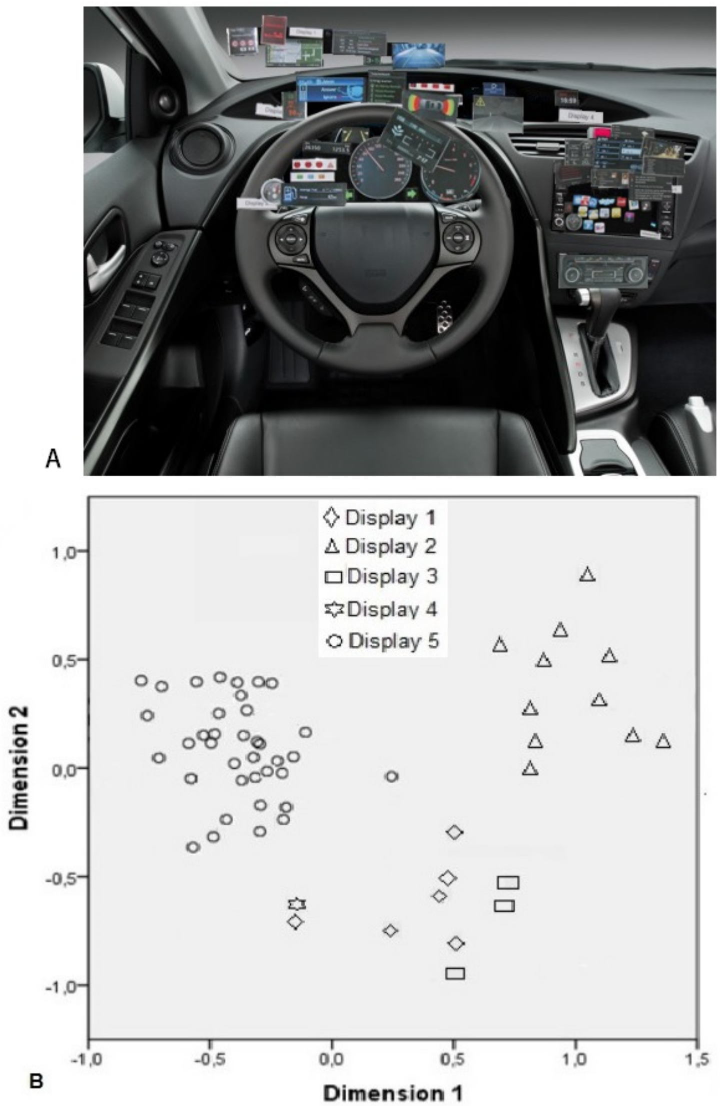

Fig. 5. (a)Example of distribution of the vehicle functions in the given displays [47] and (b) Perceptual map with the relative positioning of all functions in the multidimensional scaling diagram [41].

devices and the road can affect driver attention, reducing the ability to maintain vehicle control and delaying and/or interrupting the cognitive processing of traffic information. As stated in the ISO 15007-1:2014 - "Road vehicles measurement of driver visual behavior with respect to transport information and control systems", glance duration is usually thought of as being the measure that best captures the time necessary to extract and decode the presented visual stimulus. Even if safety is the main objective of intelligent vehicles technology, some systems that do not consider component integration can increase visual distraction, cognitive load, errors and annoyance for users [31].

Simulations and models [51] have been created to investigate the visual demand required to interact with in-vehicle systems. These tools assess visual workload, comparing different kinds of information visualization, such as route information [23], or navigation, email and communication modules [20].

4 Autonomy in Vehicles

Intelligent vehicle functions support tactical and operational driving tasks as part of ADAS. Some examples of this include: anti-lock systems that allow a motor vehicle to maintain adherence with the road surface; adaptive cruise control systems that detect the speed of surrounding vehicles, automatically adapting the vehicle's velocity to traffic; and a variety of sensors based on vision, radar, infrared or laser that are capable of detecting objects that might jeopardize road safety. Detection of other vehicles, pedestrians or other vulnerable road users (VRU), as well as driver monitoring, are some of the core areas of intelligent vehicles.

As previously mentioned, some co-ADAS rely on cooperative messages broadcasted using vehicle-to-vehicle (V2V) and vehicle-to-infrastructure communication (V2I) (V2X, collectively) to sense the surroundings. According to the US Department of Transportation (USDOT), many connected vehicle (CV) application concepts have been developed through prototyping and demonstration in recent years. A classification of these connected vehicle applications within the CV Pilot Deployment Program is listed in Table 2.

A system to augment the visual perception of the road in an overtaking maneuver based on V2X technologies was presented in [38]. The system used Vehicular Ad Hoc Network (VANET) technology to provide a video-stream of the view from the front of a leading vehicle to a rear vehicle and was particularly helpful in cases of long and vision obstructive front vehicles. The visual display was located inside the vehicle. A projection through a head-up-display (HUD) [21] conveyed the information in a later version of the system and which took into account the length of the vehicle ahead. This idea to enhance road safety was adopted by Samsung in 2015 and posted in the blog Safety Truck [10].

Research on vehicles with conditional automation [9] that are equipped with automated functions is advancing and more and more reports about vehicles that are able to operate autonomously for some portions of the trip are being released.

Table 2. Classification of the most recent connected vehicle applications sponsored by the USDOT CV Pilot Deployment Program (adapted from [52].)

V2V Safety	V2I Safety
Red Light Violation Warning	Emergency Electronic Brake Lights (EEBL)
Curve Speed Warning	Forward Collision Warning (FCW)
Stop Sign Gap Assist	Intersection Movement Assist (IMA)
Spot Weather Impact Warning	Left Turn Assist (LTA)
Reduced Speed/Work Zone Warning	Blind Spot/Lane Change Warning (BSW/LCW)
Pedestrian in Signalized Crosswalk Warning (Transit)	Do Not Pass Warning (DNPW)
	Vehicle Turning Right in Front of Bus Warning (Transit)

In conditional automation the vehicle's control is relayed back to humans through a Take Over Request (TOR) in situations that the automation is not able to handle. To this end, it is essential to assess the driver's state, their capabilities and the driving environment at the time of a TOR, as the potential boredom and road monotony associated with higher automatism of vehicles might lead to a reduction in driver situational awareness [37].

Attempting to address this need, the use of continuous, in-vehicle visual stimulus to reduce driver reaction time after a period of hypovigilance was studied in [19]. Relying on peripheral vision, the authors implemented and tested an unobtrusive method based on luminescence. They showed a tendency among drivers to respond faster to a TOR when their peripheral vision detected the stimulus.

To monitor the driver and the road conditions a mobile application can be used as backup system and issue a warning to avoid inattentive driving in the event of a TOR as suggested in [15] and latter extended in [16].

How other road users are going to interact with fully autonomous vehicles in different scenarios is not known yet. Most of the research concerning this question has been based on simulated scenarios, including working technical systems operated by a human operator (Wizard of Oz (WOZ)) or survey studies (i.e. [54], [22], [34]. However, the authors in [26] performed a field test with driverless, fully autonomous vehicles through a smartphone application that indicated to pedestrians that an autonomous vehicle was approaching. The application was intended to develop a trust in the autonomous vehicle technology. Results showed that the application supported the pedestrians in the verification process of trusting autonomous vehicles as a reliable, safe technology. Figure 6 shows the evaluation process of the application as a means to trusting autonomous vehicles.

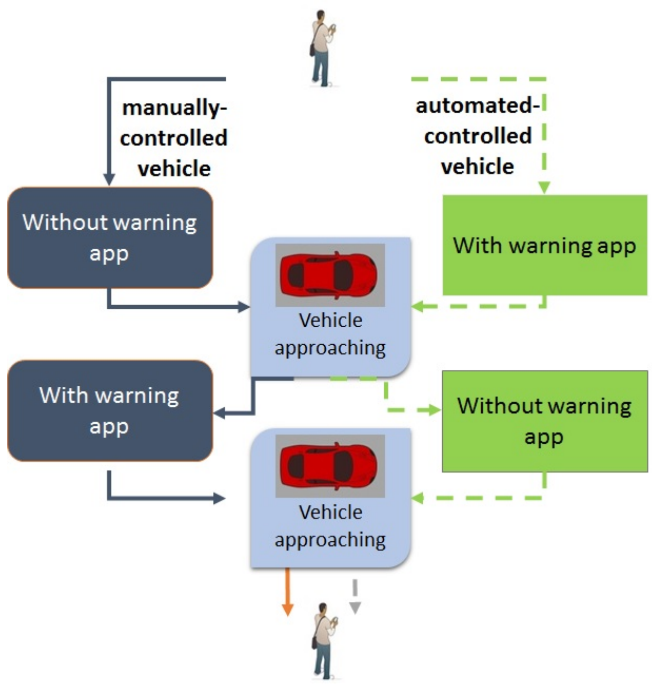

Fig. 6. Evaluation process of the application intended to develop a trust in autonomous vehicle technology [26].

5 Conclusion

Human factors in an automotive context have been researched extensively in recent years as they are decisive in road safety. This paper provides a concise introduction to the most important human factors related to road safety and addresses interaction design principles that heavily emphasize UCD, problems of distraction and workload and visual perception.

Some of the most valuable metrics for testing ADAS have been introduced as well. The information presented here provides the reader with the background, a variety of approaches and an example of applications of the most current and important concepts in the interaction with intelligent vehicle technologies.

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