# The User and the Automated Driving: A State-of-the-Art

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**Abstract.** Automation in the road transport system is coming faster than expected being influencing and shaping the future of mobility. However, very few is known about the impact of automatic driving on traffic and how drivers will accept, use, trust and interact in traffic when driving a vehicle with a certain level of automation. Additionally, most of the potential users have unrealistic representations of autonomous vehicles, the driver's role in automation or the impacts of full automation on the road transport system. Aiming at better understanding the drivers' behavior when dealing with automated driving, this paper addresses the following issues based on a state of the art on automated driving: drivers' preferences for the automation levels across different categories of drivers; limits of the technology; needs for changes in traffic laws, as well as licensing and training; driver's promptness to resume the vehicle control following a long period of autonomous driving.

**Keywords:** Automated driving · Human factors · Trust · Overreliance · Takeover · Situation awareness · Public awareness

## 1 Introduction

Automation represents a major technological advancement influencing and shaping the future of mobility. However, automation won't replace human activity but instead it will impose new demands to the human driver or user. This requires continuous research on human factors issues towards the prevention of risky behaviors and avoidance of misuse and disuse.


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Automation in the road transport system is coming faster than expected but most of the potential users have unrealistic representations of autonomous vehicles, the driver's role in automation or the impacts of full automation on the road transport system. It will be necessary that users will appropriate the current innovations in this field, develop trust on their use and the required willing to use and pay for it. There is still much to research and a long run towards a fully connected and automated road system.

Comparing to the technological development in aviation, where the automation of several components aims at assisting the pilot or assuming a certain level of control over the aircraft, automation in the road transport system introduces interesting perspectives in terms of human-automation interaction. Whilst aviation is a very closed system operating under very strict international regulations and being controlled and operated by highly skilled and experienced professionals, the road transport system is totally open to a great diversity of users (pedestrians, riders, drivers, etc.) just controlled by traffic laws under a poor supervision. Thus, the introduction of automation into the road transport system, requires new regulations and intensive public awareness under the required human- and technology-based supervision.

## 2 Learning from the History of Automation in Aviation

Learning from the history of automation in Aviation is a starting point to understand the risks and costs of automation in road vehicles. In the Aviation sector, the increased automation came with some cost. On one hand, it has not been easy for pilots to understand what the automated systems were doing, but they have been taught to remain responsible for taking over when the automated systems reached their functional limits or malfunctioned. On the other hand, pilots were encouraged to use automation towards the exclusion of manual flight controls, which were leading to a potential risk of losing their manual flight skills. Systems that alert pilots to hazardous conditions (e.g., proximity to the ground or to other aircraft) have contributed significantly to aviation safety despite those initial challenges. These systems had initially a high number of false alarms, which led pilots to develop a low level of trust on them.

Nevertheless, great improvements were made in terms of better sensors, as well as improved and standardized interfaces allowing for a better understanding and enhancing awareness. These improvements led to more reliable and robust systems that increased the pilot's trust and the willing to using them. With the nowadays development of computer technology, automation in aviation increased the complexity in the cockpit with gains in safety. Thus, for the operations safety and efficiency, modern aircrafts are increasingly dependent on automation, which have some advantages and safety challenges [1]. On the one hand, automation relieves pilots from repetitive and non-rewarding tasks, for which humans are less suited; on the other hand, these conditions change the pilots' active involvement in operating the aircraft into a monitoring role, which humans are particularly poor at doing effectively or for long periods. As a consequence, there is a workload decrease, changing the pilots' active involvement in operating the aircraft into a monitoring role, which humans are particularly poor at doing effectively or for long periods. These situations have a potential to decrease the pilots' situation awareness and, in consequence, to compromise their promptness to takeover [2]. Actually, as above-referred, the pilot is trained to remain always responsible to takeover when the automated systems reach their operating limits or malfunctioned. Compared to the road context, automated vehicles are running out of specific or updated regulations; on the contrary, several commercials show the driver working, reading or sleeping at the wheel of an automated vehicles.

## 3 Driving Automation

Being the road transport system totally open to a huge range of users sharing the road environment, just submitted to traffic laws, but under poor supervision and enforcement, additional research and testing needs are emerging in terms of safety and security issues and public awareness about such new challenges on the road. The limits and risks of the available technology are known but research on human-automation interaction is still required and the reasons are twofold: on one hand, many systems have problems with implementation, human-system integration and performance when used in the real world; on the other hand, higher expectations have been created on such technology giving rise to unexpected behaviors, risky situations and even accidents. This means that the life cycle of the system development was not complete and the system maturity and readiness to use was not accomplished. Even if any incident or accident could be directly caused by unacceptable user's behavior, the lack of a system maturity assessment will compromise the system readiness for use and the overall system capability in its expected operational environment.

The use of any automated system requires more knowledge than the use of a mechanical system for the same use. This means that driving an automated vehicle or riding a self-driving vehicle will require a different level of knowledge and understanding of the system functioning. This is similar to being working at a high technology system context, which targets high educated and digital skilled employees. An automated vehicle requires understanding of the technology limits and the driver's promptness to takeover when requested. Thus, the idea of a person at the wheel being working, watching a movie or sleeping is totally wrong and requires an urgent and serious public awareness about the limits and related risks of driving automation.

### 3.1 The Risks and Limits of the Technology

Recent literature discusses the main hurdles to wide adoption of fully autonomous driving, among which the vehicle technology's level of maturity [3] and its constraints and limits, mainly at level of the physical and social world perception [4]. These issues pose new challenges in terms of accuracy, reliability and human (driver) trust in advanced technology vehicles [5]. Despite this fact, autonomous driving and its technology have been attracting economic and industrial interest for years and, for instance, commercial cars include increasing levels of driver-assisting systems year after year [6]. In light of these developments, optimistic estimations predict that by 2030 AV will be entirely reliable to replace most human driving [5]; but until then there are some technical challenges and limits to face at present [4, 5, 7]. Therefore, the debate on these technical limits is paramount, and it should be as broad as possible, since it is expected that AV will be present in all spheres of life that demand mobility services.

The body of literature on the limits of AV tends to report different kinds of current constraints, which we may define in two complementary dimensions: (1) the technology design and its status in relation to the human activity in terms of the role assigned to the human in the presence of the automation technology; (2) and the implementation of technology in the real world, as a dynamic open system characterized by obstacles and unexpected events.

**Technology Design.** The exponential progress in new and intelligent technologies of automation has already produced impacts on the labor market and employment or even on the social protections [8]. Furthermore, in some cases, recent debates about the impacts of technology in the work activity have shown that the progress of technology and the growth of workloads may go hand-in-hand [9]. Past and current trends on the technology's design, design and development seem to understate the role of human activity, as a "second-class" [10] component of the system. As automation gets better and better (i.e., the "first-class" component), people are asked to come into play only when the technology fails; but in these situations, it is expected that human activity offsets the flaws in according to the requirements and dictates of the technology [9]. Below two situations are highlighted in the literature that can contribute to the limits issued from technology-centered design approaches:

1. Whenever the separation between the design of technological system and its implementation/execution is reinforced. If from a technological point of view, AV are practically ready to be used, the human factor seems to be the "adjustable variable" in order to assure the system reliability. In this view, the notion of human "resistance to change" is thus modified [11], not as an intrinsic trait of the human factor but as a condition determined by the way the system is designed and developed.
2. Whenever the technology is seen as something that is accepted vs. refused by the user [12]. In this case, the technology is a resource that people will accept to use if the internal conditions (attitudes, cognition, mental models and perceptions) and external conditions (level of satisfaction, context) are favorable. Unlike, in the symbiotic approach the technology is seen as an extension of the human factor. Technological design and development have underlying the notion of human-technology interface as a continuum. The technology is not thus an end in itself but acquires a sense of a constitutive element of human activity.

From these two positions we can see that automation does not mean a direct reduction or demise of human activity. On the contrary, it raises other fundamental questions about how technology changes the nature of activity, by transforming it. Hence, the human factor is now asked to perform new regulations in the face of those problems and difficulties that the technological system was unable to foresee.

**Technology in the Real World.** Other authors identify a set of technical limits at present concerning the attempt to replace the presence of the driver and his human regulation. These limits illustrate the second aforementioned dimension. In the future, it is expected that vehicles autonomously drive in various situations (e.g. in complex urban settings), triggering target-oriented answers according to the unexpected events occurring in the natural environment [13]. In these situations, the automation technology should be able to make complex decisions based on the information obtained through automotive sensors, including the perception of the environment [6, 14, 15]. From the technological standpoint, here is precisely one of the main hurdles for the implementation of higher levels of driving automation, i.e., the understanding of the spatial-temporal relationship between the vehicle and its environment [14, 16]. During self-driving, the ability to understand the surrounding is crucial for AV may shape their answers plans and, to a certain extent, even predict likely behaviors from other road users (e.g. non-automated vehicles; pedestrians). According to some authors [15, 16], both technology promoters and designers have been making efforts to attribute to technology (laser, radar and visual sensors; and path planning algorithms) the human ability of making sense of the world, that is, to sense the information from the environment[1], reacting in accordance to unexpected or uncertain events. Nowadays, this aspect is considered as an extant limitation in terms of technological issues and therefore it should guide further researches [5]. Bearing this in mind, some authors are less optimistic about the implementation of AV fully operating without any human interaction; preferring to outlook a future scenario of collaboration between human driver and automation technology, rather than the complete replacement of the human factor in driving [10, 16].

At present, in the European and Canadian contexts [17, 18], it is estimated that AV have already operated under level 2 of automation and, in some cases, on level 3 (conditional automation)[2]. Levels 4 and 5 concern the highly automated and fully autonomous vehicles, able to operate in any situation without human intervention. If the current levels 2 and 3 may be considered as infancy stages of automation development [3], how far will level 5 be? Advancements in the abilities of the vehicles perceive the surrounding environment and decision-making enable more and more to adjust the behavior of the AV to different situations liable to occur in the road [14]; but will AV ever be in conditions to match (or overcome) the human ability of perception and decision-making under best conditions [16]? Could technology be as good at making sense of the information collected from the environment as it is at collecting it?

Driving situations take place in an open system, entailing static as well as dynamic elements, and several environmental and meteorological factors, such as different levels of light or dense fog. As a multi-sensory adaptive system, human being uses these functions to make decisions enabling the recognition of patterns, dealing with unexpected events that the system is not programmed to handle, and reacting adequately to changed environmental conditions. High levels of Situation Awareness allow the driver to be permanently projecting ahead being proactive in avoiding hazardous situations instead of being just reactive. According to Endsley [19], as far as software for driving autonomy can demonstrate an ability to project and deal with the unexpected, the need for human drivers to stay engaged and able to act will remain.

[1] AV obtain the perception of external environment through laser navigation (e.g. LiDAR sensors - "Light Detection And Ranging"), visual navigation (e.g. for traffic sign recognition) and radar navigation (e.g. for distances perception) [17].

[2] According to the levels of automation defined by Society of Automotive Engineers (SAE) [4].

So far, driving software is created to deliver appropriate responses to a learned set of situations and conditions, which is not enough to deal with the unexpected. According to Pearl [20], a pioneer in the field of Artificial Intelligence, such systems are extremely limited because they cannot project new adaptations for changing situations. The ability to project future events will require much more capable software, built with models of the environment that can understand current and projected future situations upon which proactive decision making relies [21].

An additional risk related to the systematic use of automated systems that should be studied in order to be anticipated and prevented, is skill loss. It was previewed in aviation with recommendations for using manual controls once in a while. Additionally, pilots are subject to periodic trainings aiming at keeping intact their manual skills.

## 4 Acceptance, Trust and Reliance on the Automated Systems

Among other topics, there is a need for research on public acceptance and trust in automation. Schoettle and Sivak [22] carried out a survey aiming at getting the public opinion regarding self-driving-vehicle technology in three major English-speaking countries: the USA, UK and Australia, having had useable responses from 1,533 persons aged of 18 and older.

The main findings of this survey were the following: (1) the majority of respondents having previously heard of self-driving vehicles, had a positive initial opinion of the technology, and had high expectations about the benefits of the technology; (2) but the majority of respondents expressed high levels of concern about riding in self-driving vehicles, security issues related to self-driving vehicles, and self-driving vehicle not performing as well as actual drivers; (3) respondents also expressed high levels of concern about vehicles without driver controls, as well as self-driving vehicles moving while unoccupied and self-driving commercial vehicles, busses, and taxis; (4) most respondents expressed a desire to have this technology in their vehicle, but they were also unwilling to pay extra for the technology offering similar amounts in each country; (5) females expressed higher levels of concern with self-driving vehicles than males and were more cautious about their expectations concerning benefits from using self-driving vehicles.

In comparison to the respondents in the U.K. and Australia, respondents in the U.S. expressed greater concern about riding in self-driving vehicles, data privacy, interacting with non-self-driving vehicles, self-driving vehicles not driving, human drivers in general, and riding in a self-driving vehicle with no available driver controls. The main implications of these results are that drivers and the general public in the three surveyed countries, while expressing high levels of concern about riding in vehicles equipped with this technology, feel positive about self-driving vehicles, have optimistic expectations of the benefits, and generally desire self-driving-vehicle technology when it becomes available, although the majority was not willing to pay extra for such technology. However, at the time the survey was applied there was not a perfect awareness about the limits of the technology and related risks. Thus, it's now time to survey again people's attitudes, concerns, trust and willing to use and pay for these technologies.

More recently, a paper based on interviews conducted with twelve expert researchers in the field of Human Factors (HF) and automated driving aimed at identifying commonalities and distinctive perspectives regarding HF challenges in the development of AVs, has been published [23]. In this paper, Kyriakidis et al. pointed out that "many challenges pertaining to the interaction between human drivers and automated systems are yet to be resolved". Between these, are "the human drivers' levels of acceptance, trust, and reliance on the automated systems" [23].

Giving some examples of the experts' considerations about this subject, the opinion of Brookhuis [23] is that as system failures cannot be excluded, additional research should focus on public acceptance and trust in automated vehicles". In the same line, Bengler [23] says that acceptance of automated vehicles by the public is a big topic and the first of main tasks of Human Factors research is to define the acceptance criteria of human drivers regarding the automated driving functionalities. van Arem [23], considering that while the human drivers will be supervising the system and intervene, if required, they will not be allowed to be engaged in a large variety of non-driving tasks, conclude that the benefits for the consumers, as well as their acceptance and willingness to buy such automated vehicles, are limited. Also, on this point and about the SAE automation levels 2, 3 and 4, Andersson [23] raises the question: Who would like to use automation if they remain liable at all times for a system that they partially cannot control? Merat [23] says that, within the next 10 to 15 years, it is rather likely that the cost and maintenance of vehicles with automated functionalities will be quite high, which will be a major barrier towards their deployment and acceptance by the majority of the public. Finally, Flament [23] points out that "the same vehicle, depending on its environment and its access to reliable information, could allow more than one level of automation. The HF challenge in this case will be to clearly inform the driver about the possible levels of automation at any given time and place, and why this is so. This will lead to trust and acceptance of automation, but too much trust may cause overreliance together with unintended use, misuse, and even abuse".

The problem is that, so far, there is not a concerted, cohesive and cross-cutting policy on public awareness focused on automated driving or automated cars, the automation levels and the practical meaning of each one under a safety and secure umbrella. On the contrary, there is a massive advertising on self-driving cars using unrealistic images, which together lead to misunderstanding, overreliance, negative risk-taking and, sometimes, misuse. That's why there is an urgent need for updated traffic regulations and public awareness about this new era in the road transport system.

### 4.1 Overreliance and Complacency in Automated Driving

The first effect of being at the wheel of an automated car and riding in automated mode is a mental underload that can lead to drowsiness after a while; reading or watching a movie leads to a switch on the driver's attention from the road to a different object; sleeping at the wheel of an automated car following a driver's decision to do it; all these three conditions impair the driver's promptness to resume control under request. As far as a vehicle arrives into the market with a cockpit, it means that a licensed driver is required behind the wheel in order to resume the control under the system request or his/her own decision to do it, once the human is assumed to have the final authority over the automation [24]. Thus, once again, it is necessary to better know and understand the system in order to make appropriate decisions when activating or deactivating an automated mode. This requires knowledge about the system and understanding of its functioning, giving rise over time to trust in the system under pre-defined boundaries. The lack of knowledge or understanding of the system functioning and its limits can give rise to an overreliance on the system, which is a risky attitude underlying further risky behaviors.

It is also frequent to consider that the system is always running as supposed to do and that there is nothing to concern about. This attitude risks to create a path to complacency, accepting anything as normal. In the field of Aviation, it has been reported that automation-related complacency was among the top five contributing factors for accidents [25]. Experiments carried out by Parasuraman et al. [26] indicate that the operator's attention allocation strategy appears to favor his or her manual tasks as opposed to the automated task. This strategy may itself result from an initial orientation of trust on automation, which is then reinforced when the automation performs at the same, constant level of reliability. Therefore, automation in the context of the road transport system is being perceived as highly reliable, which leads to an increasing trust on the technology that is expressed in less system monitoring once no failures were expected. This is leading to the driver's overreliance and complacency in automation. At the same time, this is underlying some disseminated images of drivers reading or watching a movie at the wheel table, lying down and sleeping, among other images that are not realistic, inducing wrong representations of automated driving and lead to unsafe behaviors. This compromises the driver's promptness to resume the vehicle control following a long period of autonomous driving, reinforcing the needs for updated regulations and a serious public awareness on driving automation and drivers' behavior.

## 5 The Needs for Updated Regulations and Public Awareness

Despite the good intentions presiding at the development of automated vehicles, their increasing number sharing roads and the urban environment with a great variety of vehicles from different generations and different categories of road users, are creating new driving conditions giving rise to behavior adaptations. However, such intuitive behavior adaptations developed out of any update of the existing traffic regulations or new ones, is highly risky and open a window to compromise the initial good intentions of this fast change.

The document issued by the U.S. Department of Transportation in October 2018 "Preparing for the Future of Transportation: Automated Vehicles 3.0" [2] provides a clear and consistent approach for automated vehicles related policy, based on six principles: (1) prioritize safety, using the potential of automation to improve safety for vehicle operators and every road user being aware that new safety risks appear and must be identified and managed in order to create trust on the technology and willing to use it; (2) remain technology neutral supporting the fast development of automated vehicles and giving rise to competition and innovation as a means to achieve safety, mobility solutions and economic goals; (3) Modernize traffic regulations, eliminating outdated ones impeding the development of automated vehicles or that do not address critical safety needs; (4) encourage a consistent regulated and operational environment, building consensus among policy makers, industry and stakeholders; (5) prepare proactively the society for automation through the provision of guidance, best practices, pilot programs, and other assistance towards a dynamic and flexible automated future; (6) protect and enhance the freedom of driving each one's vehicle and sharing the road with conventional, manually-driven vehicles and other road users.

In Australia, the National Transport Commission has issued the following policy recommendations to the Transport and Infrastructure Council towards a uniform approach to driving laws for automated vehicles [27]: (1) an automated driving system that has been approved under and continues to comply with the safety assurance system will be allowed to perform the dynamic driving task when it is engaged; (2) It ensures that there is always a legal entity responsible for the dynamic driving task when the automated driving system is engaged; (3) it clarifies who is the responsible entity at various levels of automation when the automated driving system is engaged; (4) it sets out any obligations on relevant entities, including the automated driving system entity, and users of automated vehicles; (5) it provides a regulatory framework with flexible compliance and enforcement options.

Such type of regulations is missing in Europe in order to avoid compromising the good intentions of zero accidents with such technological development with an increase in road accidents resulting from missing regulations and public awareness, together with the need of a road environment compatible with that new reality.

## 6 The AUTODRING Project and the Research Methods and Tools

Driving simulators are a powerful tool to support the research focused on driver behavior [28]. The advantages of using driving simulators in this type of researches are mostly the elimination of safety and ethical issues, avoiding unexpected events. Moreover, the well-controlled environment allows the design of scenarios and experimental conditions that cannot be easily implemented in real-world. In the context of automated driving, several studies were developed based on driving simulator experiments. Regarding the study of perception and intended use of automated vehicles, and despite most of the studies were based on surveys [29, 30], Buckley et al. [31] conducted a simulator experiment in which participants experienced periods of automated driving and manual control, followed by a survey task. Nevertheless, most of the studies underlining automated vehicles that use driving simulators, are focused on aspects such as takeover of vehicle control, secondary task engagement and workload [32]. These aspects are of most relevance since until the level of full vehicle automation is reached, users of vehicle automation systems will be required to takeover manual control of the vehicle occasionally and stay fallback-ready to some extent during the drive [33].

Considering that: (1) automated driving is not yet enough disseminated or experienced by common and professional drivers in nowadays societies, particularly in Portugal; (2) and the industrial technologic development is fast and requires deep research on the use of such technology allowing for road safety improvement, trust on the technology, appropriate regulations and prevention of misuse, are addressed in this new National funded project – AUTODRIVING – together with its main purpose to contribute to the study of the driver's activity and behavior during the autonomous driving, addressing: (1) The driver's promptness to resume the vehicle control following a long period of autonomous driving; (2) the research of the takeover of vehicle control task under different circumstances, which is expected to be the riskiest driving task in autonomous vehicles; and (3) the identification of the driver's understanding of the system functioning, which will allow for the formation of trust on automation, both required for a later safe behavioral adaptation.

These objectives will contribute to improve knowledge about the driver's level of promptness to switch the vehicle control levels between the driver and the system and the influence of driver characteristics (e.g. age, sex, health state, risk perception) on his/her driver behavior and performance. This knowledge will support the development of advanced driver assistance systems (e.g. the notification interval to the takeover), which are foreseen to be tailored to the driver characteristics, by automotive and software industry and R&D agents in the field of information systems and vehicle automation.

## 7 Final Remarks and Next Steps

The state of the art on driving automation highlights the needs for research on Human Factors and driver's activity and behavior in the context of driving a vehicle with different levels of automation. Thus, in the frame of the AUTODRING Project, it is being prepared a National Survey addressing the following issues: (1) drivers' preferences for the automation levels across gender, age, education level, user group, etc.; (2) the perceived limits of the technology; (3) perceived needs for changes in traffic laws, as well as licensing and training. Following the survey, tests with users from different groups on a Driving Simulator will be carried out. These tests will integrate appropriate scenarios for the research purposes. The research focuses on Level 3 and Level 4 of the five automation levels defined by the SAE. Considering that the driving behavior is the visible output of an internal activity, the experiments to be carried out will explain the driver's behavior through the analysis of the driver's activity using complementary methods and tools.

To support the experimental design, a novel approach is proposed to be applied based on a taxonomy developed by Save and Feuerberg [34] in the context of automation in air traffic management (ATM): Level of Automation Taxonomy. The taxonomy is organized according to the functions defined by Parasuraman et al. [35] and Endsley [36]. These functions are based on a four-stage model of human information processing translated into equivalent system functions: information acquisition, information analysis, decision and action selection, and action implementation. Although being developed with ATM automation in mind, this taxonomy has been considered applicable to other contexts under automation processes as it represents a human-centered approach to automation based on the definition of generic human functions that can provide an initial categorization for types of tasks in which automation can support the human. This taxonomy is useful to guide the analysis of the driver's activity, which is decomposed for each of the four functions in driver and system activities.

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