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Successful Autonomous Vehicles Human Machine Interfaces from a UX Design perspective: A Review.

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ABSTRACT
Every day more and more tasks become fully automated. In recent years the emerging technology, *Autonomous Vehicles* (AV) have started to reach their final user, bringing to life all the promised benefits and advantages that have been announced by numerous manufacturers for years. However the bigger challenges begin, the adoption of the final user for a brand new technology while overcoming all of the automation paradox challenges. The general approach for the research and advance of the AVs has been from a technology standpoint, the current development state calls for design strategies with user needs centered requirements. To promote this technology acceptance, the effects on the user experience as a result of the new role that is being acquired (active driver vs passive passenger) must be taken into account. User Experience Design (UX) is the practice of designing with the focus on the user, considering all the possible beneficiaries of a product and creating a positive connection with the final user, fostered by the inclusion of their emotions, feelings and concerns. This paper explores the characteristics that must be integrated while designing AVs interfaces to achieve a satisfactory end user adoption.

***Keywords* -** Autonomous Vehicles, Autonomy Paradox, User Experience Design, Human Machine Interface, User Interface

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I. INTRODUCTION

What do designers and engineers need to focus on for the Autonomous Vehicles to really satisfy the user needs and at the same time meet their wants and concerns? The penetration of the Autonomous Vehicles in the market is one of the biggest challenges that this technology faces nowadays, especially for vehicles with higher levels of autonomy (L3 and beyond according to SAE scale [1], [2]). By being the most revolutionary evolution that mobility Technology has seen in years, little to no research, recommendations or specific standards exists that can help the industry understand in an efficient way the minimum characteristics that the user interfaces incorporated on the Autonomous Vehicles must have in order to improve their success rate. According to Riener et al [3] UX Design is one of the most powerful tools that AVs could leverage on to reach a higher penetration on the market.

II. CHALLENGES ON THE HUMAN-AUTOMATION INTERACTION

Lissane Bainbridge [4] published forty years ago what we know today as the “Paradox of Automation". Automated systems reduce or eliminate the need for human effort, however human intervention becomes more critical when errors or unexpected situations happen.

The way human cognition and emotions work makes it almost impossible for operators to follow up with the automated tasks or processes, which authors [4], [5], [6], [7] refer to as being “out of the loop”.

Some of the challenges derived from the aforementioned concepts can be listed as:

1. Achieving full transparency between automation behavior and the operator.
2. Keeping the operator on the loop or speed up his/her reincorporation to the task.

3. Matching Automation strategies to user needs, wants and concerns as well as to technological advancements.
4. Incorporating human cognitive behavior into the design in order to minimize the initial increase on the cognitive workload due to the driving task nature change. In example: expert driver using only the resources on his subconscious level to perform the driving task to expert driver using the resources on his reflexive (conscious level) to perform the effective monitoring (of the automated system) task.
5. (Derived from the previous points) Regulating the trust level on the automation: Distrust increments the cognitive workload and negatively impacts acceptance. Over-trust drives to failure on effective reaction to a Take Over Request (TOR) from the automated system, potentially enabling dangerous situations and consequently negatively affecting adoption.

A fair addition to these challenges are the public perception and acceptance of the AVs and its measurement. On one hand, as of today, the only mean that the average end user has to evaluate the product is via the press, social media and marketing strategies; and on the other, academic and industry research on acceptance are based solely in prototypes, mockups or virtual reality simulations [8], [9], [10] given that few or non-fully AVs are available for the wider audience.

According to Mara and Meyer [11] the identified variables for AVs acceptance can be divided into three determinant categories:

- User specific: Sociodemographic and personality traits.
- Car specific: Perceived safety, system performance and appearance.
- Context specific: Road infrastructure.

Therefore it can be inferred that one of the main focal points for the adoption of the AVs is the research on human needs and the requirements for the adoption of new technologies. In 2019 a Multi-Level Model on Automated Vehicle Acceptance (MAVA), an evolution of the classical Technology Acceptance Models specifically developed for the acceptance of AVs, is proposed by Nordhoff et al [12]. This holistic model includes individual differences, perceived safety, performance expectancy, social influence, hedonic motivation, perceived benefits and risks as evaluation factors to determine AVs acceptance.

III. DESIGNING USER INTERFACES THROUGH UX TO PROMOTE AVs ACCEPTANCE.

With the increase of technology in everyday activities there is no hour that passes by without the interaction between a human and a machine, designing this “bridge” generally referred as Human Machine Interface (HMI) to achieve a seamless communication becomes essential, but even more so when the machine is new to the user.

Literature concurs in the following general recommendations when designing HMIs for AVs:

1. Level of Autonomy: User needs change depending on the level of autonomy, HMI design should be specific to it and not a “catch all”.

1.1 SAE L0-2: According to SAE taxonomy, in these levels the human is always responsible for the driving task and the system is only providing different levels of support and assistance; therefore the HMI should be designed with the objective of making the human the best driver possible, increasing the effectiveness and safety.

1.1.1 Emotion Regulation: Improving driver performance by using HMI for emotion regulation: Mood tracking, empathizing agents or car environment regulation according to driver or environment state.

1.1.2 Attentive User Interfaces (AUIs): To manage and match the non-task related information and the task related information provided to create balance between attention allocation and demand for a successful task performance. In example: Blocking, limiting or denying cellphone interactions or alerts while activities with higher degree of complexity are being executed.

1.1.3 Multimodal Displays: The mixed use of visual, auditory and haptic cues has been found to be a more effective way to deliver important information to the user [13]. However, deeper research on the adequate combination, relevance and amount of signals is necessary. In example, the use of sound, other than for emergency calls, has yet to be further studied, especially for higher levels of autonomy where the enjoyment of the driving experience no longer comes from the driving task itself.

Some automotive manufacturers are currently using haptic cues to grab users attention in case of emergency situations, however while they are highly effective at improving the driver skills for safety, they do not create a pleasant driving experience. As an example, test users of vibrating seat anti-collision systems have reported the technology has improved their driving style but quickly become a nuisance they are tempted to turn off [14].

1.2 SAE L3: Probably the most difficult level of autonomy in terms of human cognitive capabilities and experiential factors, the human is no longer responsible for the driving, nevertheless should be able to take over the task safely and effectively in case of a system request. The focus of the HMI design should be on keeping, supporting or improving the human situation awareness for an effective task take-over while also enabling and improving the enjoyment of the whole experience.

While AUIs and Multimodal interfaces improve situational awareness speeding the user response for a TOR and potentially mitigating cognitive overload, it can be inferred from the ATHENA display evaluation [9] that their use do not necessarily have a positive impact on the user experience. The amount of TORs is proportional to the detriment on the task enjoyment and AVs acceptance. Additionally, research on the type of mixed cues in multimodal displays to deliver the adequate sense of urgency to support the fallback driver task is still needed.

1.3 SAE L4 & 5: The human is no longer responsible for the driving task, the system might send TORs in L4 but will always be able to bring the car to safe passage by itself whereas L5 will not send TORs at all. HMI design should satisfy the stimulation and autonomy needs that could be stripped from the user. In lower levels of autonomy the enjoyment comes from the driving task itself, opposite to higher levels where the user experience comes from being driven; hedonic affective factors and means of promoting enjoyment and stimulation are the prime need. In example the car multimodal displays could now even include olfactory cues to stimulate the senses.

2. Design Methodologies: Even though current design methodologies are dictated by the state of the technology and industry challenges and guidelines, a more holistic approach that encompasses the following is recommended:

2.1 Designing hand by hand with the final user (Participatory Design and Co-design)

2.2 Establishing user needs or case based requirements (Match UT model [8], X-Model [8], DAUX Framework [9]).

2.3 Applying exploratory studies for prediction behavioral patterns, focused on psychological needs and hedonic factors.

2.4 Triangulating psychological measurement methods, qualitative data, usability engineering data and quantitative data.

3. User definition: It is not recommended to solely base the AVs HMI design approach on a single set of user characteristics but rather to cross analyze socio-demographic data, user expected benefits, tech related anxieties, tech savviness and experience, personality and cultural traits, travel circumstances and driving style to mention some. Mara and Meyer [11] noted, as a result of their literature review, that there are statistical changes on determinants of user acceptance while interlacing user characteristics. In example, picture a female neurotic user with high internal locus of control, high technology and car savviness. The first mentioned characteristics correlate to lower acceptance rates of AVs, while the second set to higher acceptance rates, which may sound contradictory, but in a deeper analysis it is understood that the more knowledgeable a user is about how something works, less anxiety is presented; mitigating the gender and personality traits [11]. Even when this data was analyzed for the AVs acceptance, the same concepts are applicable to the design of the HMIs, the more transparent the use of an interface is for the user, the higher the success rate.

IV. FUTURE INTERFACES

Gestures, Ultrasound, Mid Air Haptics, Virtual and Augmented Reality are all promising resources to improve both, the drivers experience and performance by managing cognitive workload on AVs, but they all also present some challenges, first the technology is not at the optimal level for implementation and the development of accurate mental models is still undergoing, people are just not used to them or interacting with them. Future research would be required when these and other technologies become available on AVs.

V. CONCLUSION

We have shown how current HMIs in AVs are surely helping to make the driving task safer, however not necessarily more enjoyable; what would happen if despite all the advantages, the end user does not resist the urge of turning off all of the “support” features in pro of the self comfort but in lieu of everyone else’s safety? The topics explored here demonstrate how a correctly and thoughtfully designed HMI integrates all the necessary and relevant elements for an enjoyable UX. The need for specialized HMIs is also discussed, exploring how different automation levels have a direct impact on the number as well as the difficulty of the tasks that the end user is expected to perform.

As the AVs become more accessible and advanced, designers will have the opportunity to evaluate real user interactions with this technology and adjust the necessary design principles for an effective HMI and an enjoyable UX, as at the moment this article is being written, the HMI evaluations are highly influenced by trust and performed via simulations.

It is recommended that future work includes exploratory studies of current mental models applied to AVs HMIs, looking to understand and quantify the real benefit and their relevance to the intended task.

REFERENCES

[1]. J. Shuttleworth, SAE J3016 Levels of Driving Automation. SAE Mobilus [online]. January 2019. [Accessed 19 August 2022]. Available from: https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic

[2]. SAE INTERNATIONAL, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles J3016_202104. SAE Mobilus [online]. April 2021. [Accessed 19 August 2022]. Available from: https://saemobilus.sae.org/content/j3016_202104

[3]. A. Riener, User Experience Design in the Era of Automated Driving (Springer Nature, 2021. ISBN 9783030777265.)

[4]. L. Bainbridge, Ironies of automation. Automatica, 19(6), 1983, 775–779.

[5]. M.R Endsley, Designing for Situation Awareness: An Approach to User-Centered Design (Boca Raton, FL: CRC Press, 2016).

[6]. M. Baumann, J. Krems and L. Heinrich, Automation, Situation Awareness and Mental Workload, in A. Riener (Ed.), User Experience Design in the Era of Automated Driving, 1 (Springer Nature, 2021) 35-68.

[7]. D. Norman, The Design of Everyday Things: Revised and Expanded Edition (New York, NY: Basic Books, 2013).

[8]. L. Rittger and T. Schrader, Novel User Experiences and Human Centered Development in Vehicle Design, in A. Riener (Ed.), User Experience Design in the Era of Automated Driving, 9 (Springer Nature, 2021) 315-348.

[9]. A.K Frison and A. Riener, The "DAUX Framework" A Need-Centered Development Approach to Promote Positive User Experience in the Development of Driving Automation (Ed.), User Experience Design in the Era of Automated Driving, 10 (Springer Nature, 2021) 349-392.

[10]. M.A Gerber, M. Faramarzian and R. Schroeder, Inception of Perception-Augmented Reality in Virtual Reality: Prototyping Human-Machine Interfaces for Automated Driving, in A. Riener (Ed.), User Experience Design in the Era of Automated Driving, 18 (Springer Nature, 2021) 652-687.

[11]. M. Mara and K. Meyer, Acceptance of Autonomous Vehicles: An Overview of User-Specific, Car-Specific and Contextual Determinants, in A. Riener (Ed.), User Experience Design in the Era of Automated Driving, 3 (Springer Nature, 2021) 94-137.

[12]. S. Nordhoff, M. Kyriakidis, B. Van Arem and R. Happee, A multi level model on automated vehicle acceptance (MAVA): a review based study. Theoretical Issues in Ergonomics Science, 20(6), 2019, 682-710.

[13]. J.H Yang, S.C Lee, C. Nadri, J. Kim, J. Shin and M. Jeon, Multimodal Displays for Takeover Requests, in A. Riener (Ed.), User Experience Design in the Era of Automated Driving, 15 (Springer Nature, 2021) 543-575.

[14]. M. McFarland, My seat keeps vibrating. Will it make me a better driver before driving me insane?. Washington Post [online]. June 2015. [Accessed 30 August 2022]. Available from: https://www.washingtonpost.com/news/innovations/wp/2015/01/12/my-seat-keeps-vibrating-will-it-make-me-a-better-driver-before-driving-me-insane/