Re-inventing the Journey Experience – A Multifaceted Framework To Comfort in Autonomous Vehicles

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Abstract Future vehicles provide scope to completely re-invent the journey experience. Technological advances have enabled fast progression of driving automation which has the potential to deliver efficient, accessible, sustainable and clean transport systems. Level 4 autonomous vehicles provide an exciting opportunity for drivers and passengers to engage in many activities unrelated to the driving task (e.g. reading, work communication/social networking on mobile technologies, relaxing, watching films etc.) leading to benefits in terms of comfort, pleasure and productivity. There has already been a lot of work looking at the active safety systems autonomous vehicles will need to use as well as the accompanying Human Machine Interface (HMI). For example, studies that look at the time it takes to hand over control from the vehicle to the occupant, and from the occupant to the vehicle. However, little is known regarding the nature of the secondary activities that drivers will want to undertake, and how this will impact occupant comfort, the vehicle architecture, its features and functional safety systems. To understand the ergonomic and engineering impact, first we must capture and fully understand user needs and their preferences in terms of the type of activities that could be undertaken in-vehicle.

Re-inventing the journey experience is a research program addressing the lack of research around the user experience of autonomous vehicles. The main aims of the program are to: (1) understand potential for improving the travelling experience; (2) understand what the ergonomic, legislative, safety and comfort constraints are in order to identify design constraints; (3) understand how design innovations can support new occupant requirements. This paper presents a multifaceted framework which aims to guide researchers and industry professionals to more pragmatic vehicle concepts.

Keywords: vehicle design, autonomy, user experience, comfort

1 Introduction

The automotive industry is approaching a revolutionary shift towards both electrified powertrains and autonomy. These two major developments are expected to improve road safety, reduce traffic congestion and increase occupant productivity as well as many other benefits [1]. Electrified powertrains will create a smoother ride as the engine will produce less vibration and noise, presumably leading to greater levels of comfort. Autonomy will allow the occupants to detach themselves from the driving task and spend that time relaxing, being productive and socializing.

It has been argued that comfort and discomfort are not opposites and can exist simultaneously. Comfort can be defined as “a pleasant state of well-being, ease, and physical, physiological and psychological harmony between a person and the environment”, while discomfort refers to “a state where one experiences hardship of some sort which could be physical, physiological or psychological” [2]. Traditionally, passenger comfort has encompassed air quality, sound and noise, temperature and vibrations [3]. However, with the new paradigm shift toward electrified and autonomous vehicles, there are some new factors to consider. Elbanhawi (2015) argues that these are naturality, disturbances, apparent safety and motion sickness [4]. There is a lot of evidence to suggest that an autonomous vehicle can decrease the level of discomfort of a journey. Drivers will be able to re-adjust their posture when they are not required to drive which will reduce the levels of discomfort [5]. Another potential benefit is an autonomous vehicle could reduce anxiety for nervous drivers or allow the driver to rest and detach from the driving task. There could however be some negative implications for an electrified and autonomous future. Autonomous vehicles could be bullied [6], the occupants could feel range anxiety [7] and a badly designed interface could lead to confusion and disuse [8].

The idea that you could be more productive or do another activity when in an autonomous vehicle is one area of research that is still being explored by research institutions, manufacturers, suppliers and universities. This is often referred to as NDRTs, or Non-Driving Related Tasks and it is believed to be one of the key benefits of using an autonomous vehicle. Previous studies that have been investigating NDRTs have used a variety of methods to determine what the occupant will be doing including surveys, interviews and observations. Some studies have the luxury of using a driving simulator [9] whereas others use road legal vehicles and conduct research within the context [10]. There are however some limitations with how some of the experiments were run. In a longitudinal study by Large et al [5], they wanted to understand the range of activities and items that would be used in highly automated vehicles. The study took place in a medium-fidelity, fixed based driving simulator (Audi TT). It identified some NDRTs as well as the items that participants are likely to use in an autonomous vehicle as well as changes to their physical posture. However, the study did not deal with the risks of future legislation and crash safety, for example the placement of items in relation to airbags. This extra factor could have changed how some participants reacted to the test conditions. Other studies have looked at the broader topic of autonomous vehicle user experience where they have faced similar challenges in addressing future safety and legislative concerns. Another often overlooked consideration when designing an interior of an autonomous vehicle is motion sickness. A large and growing body of literature has investigated the effect an autonomous vehicle will have on an occupant’s physical wellbeing and each of them have generated various design recommendations.

The trend of an aspirational, and often unrealistic vision of an autonomous vehicle has most likely stemmed from OEMs (Original Equipment Manufacturers). OEMs have been producing future vehicle concepts that aim to draw customers into the brands vision. One more recent example of this is the Mercedes F015 [11]. The Mercedes shows the front seats facing the rear seats to create a more social and productive space (example shown in figure 1). This is also shown in the Panasonic concept shown at CES 2017 [12] where they have deploying tables with built in displays. Although the primary purpose of these concepts were to build brand awareness and perception, they have potentially had the unintended effect of misleading researchers to believe that such concepts could be designed safely and within regulation.

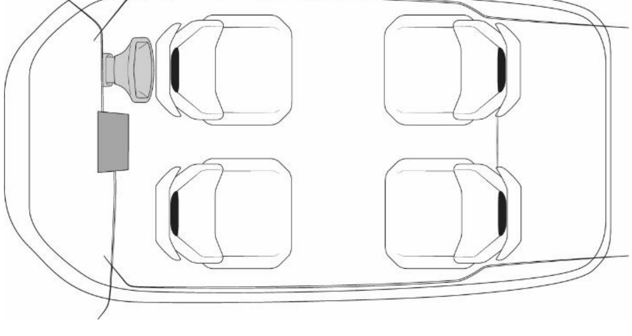

Fig. 1. Concept interior layout showing rearward facing seats.

It is still being debated as to when vehicles will be able to drive fully autonomously, and where there will be no need for a steering wheel [13]. This has been defined by SAE as a ‘level 5’ autonomous vehicle [14]. There will need to be a gradual progression from a ‘level 4’ vehicle to a ‘level 5’ as the latter will require all roads that the vehicle will drive on to be mapped and would require the vehicle to be much more advanced. It is likely that vehicles will be ‘level 4’ for a much longer time, where there is still a need for the driver to take over control for more difficult roads.

This paper will review the published research conducted in the areas of occupant physical wellbeing, including crash safety legislation and motion sickness, and handover of control and create a list of design recommendations for future research to use. This will be restricted to highly automated vehicles that are not yet at full self-driving capability (SAE level 4).

2 Mental Well-being

When a vehicle becomes fully autonomous, or highly autonomous, the occupant will become mentally and physically detached from the task of driving. This could give an opportunity to the occupant to improve mental and physical health. For nervous drivers, it could reduce the stress and anxiety of a journey and for commuters it can give the opportunity to relax after a day at work. There are however some potential added stresses that autonomy can introduce. Especially for early autonomous vehicles, the need to be aware of your surroundings and the responsibility to perform a safe handover of control are both new challenges that come with the technology.

With the freedom of time inside an autonomous car, there is a risk that the driver can become overloaded with non-driving related tasks (NDRTs) and become distracted, reducing the situational awareness. Several studies have investigated the effects NDRTs have on situational awareness and handover of control (HoC) times [15][16][17] and have shown that there is a negative effect on situational awareness when a NDRT is introduced. This is also shown in earlier studies by Giesler & Muller [18], and Lorenz et al., [19] who identified that visual distraction is one of the most important factors related to a safe HoC. As well as over-stimulation, there is also a risk to being under-stimulated [20]. If the driver becomes tired, and falls asleep, the time to regain situation awareness will increase, and this will potentially increase the time required to regain situational awareness over NDRTs [21].

There has been a large and growing body of research that is aiming to identify the handover of control requirements for autonomous vehicles. This work will ultimately result in a recommended handover of control time for manufacturers to use and standardize. This will be for both a safe HoC for transitioning into autonomy as well as into lower autonomy levels, or full manual driving. Kim & Yang (2017) argue that the minimum HoC time will vary depending on the event, for example, roadworks or a car pulling out of a junction [22].

One important, and often overlooked aspect of handover of control is the time it takes to securely stow the items used during NDRTs. Not only will this add to an increase in time to situational awareness and control of the vehicle, it could also have a negative effect on physical well-being in a crash situation. It could be argued that the added pressure of stowing items in a HoC situation will increase the level of discomfort an occupant will feel. Therefore, it is recommended to make the stowing of items a priority in autonomous vehicle ergonomic and user experience studies for both industry and academia.

3 Physical Well-being

Physical wellbeing is arguably the most important factor when considering the perception of comfort in an autonomous vehicle. It is likely that the safety regulations will not change considerably when there are large numbers of highly automated vehicles on the road. Due to this, designers and engineers will be constrained by such regulations which will have an impact on occupant comfort. Below are factors to consider when designing a comfortable autonomous vehicle.

3.1 Motion Sickness

As vehicles progress to become autonomous and electrified, the occupants will have the time to engage in NDRTs. This could potentially lead them to be visually and mentally distracted as well as being outside of the nominal seating position, for example, the use of a display is essential, to watch a movie or to do some work. Kuiper et al (2018) investigated the positioning of vehicle displays, and if it influenced motion sickness. They found that a high-mounted display is preferable to a low-mounted display and this significantly reduced motion sickness [23].

Car-sickness is a form of motion sickness that two-thirds of people will have suffered from at some point in their life [24] and reducing the likelihood of motion sickness will reduce the levels of discomfort an occupant will face. Future research studies should consider the effect their concepts will have on such a fundamental part of physical wellbeing in a vehicle.

Social scenarios are often depicted in vehicle concepts and studies by researchers. They often come to the conclusion that seats should face each other such that the front seats rotate 180° [25]. This however has been found to increase the likelihood of motion sickness in city driving [26]. Sleeping, or relaxing in an autonomous vehicle could have a positive effect on motion sickness as being in the supine position (and sleeping) has been shown to reduce motion sickness [27].

3.2 Seat belts

Seat belts are a fundamental part of the vehicles passive safety system. It is currently required for all new cars to be fitted with seat belts, and they have been proven to reduce the risk of serious and fatal injury by between 40% and 65% [28]. It is unlikely that regulators will decide to de-regulate the use of seat belts, and so should be assumed to be a part of future vehicles.

There is a potential added complication however when NDRTs are introduced. Most seat belts are anchored to the B pillar. This is because it is a structural support for side impact regulations and is strong enough to also anchor an occupant through the seat belt. With the option to disengage from driving, occupants may want to recline the seat, move rearward and create more space in front of them, or partially rotate to be more social and increase the levels of comfort. By being outside of the nominal seating position, and with the seat belt anchored to the B pillar there is an increased risk of serious injury in an accident. This is shown in a study by Dissanaike et al (2008) where they evaluated the accidents of drivers who reclined the seat [29]. Therefore, it is recommended that researchers make assumptions that the seat belt anchor point can be built into the seat itself.

3.3 Seat rotation

Current passive safety systems are not designed for the occupant to be moving outside of the nominal seating position. This includes fore/aft adjustment as well as seat rotation. Full rotation, as shown above, can increase the likelihood of motion sickness [26] and so should be ruled out. There is also an increased complication with designing the safety system. There could be two separate systems for the two seating positions. However, this will not cover the situation of a crash during rotation, and such seats will need to be set either forward facing or rearward facing before the journey, which could limit the usability of the vehicle (e.g. crossing geofenced locations).

Small rotations could be accommodated (shown in figure 2), and a safety system designed for this. There is no evidence that a small rotation of up to 10° will increase motion sickness or risk the occupant's health in a crash and so this would be one way to increase the sociability of the vehicle cockpit. Therefore, it is recommended that researchers limit seat rotation in future autonomy studies.

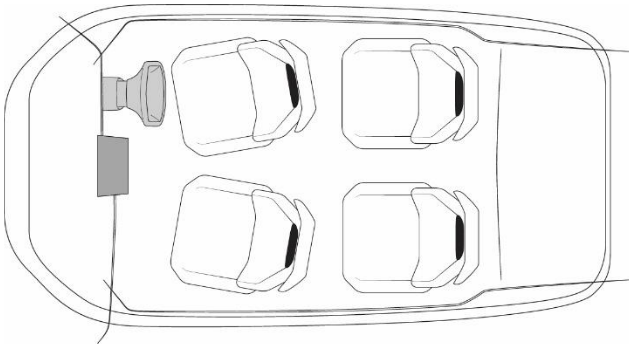

Fig. 2. Vehicle concept showing inward rotated seats.

3.4 Airbags

Airbags are a key element of the safety system, however they are not required in Europe [30]. Front seat passenger airbags can help to reduce the risk of fatal injury by 68% when combined with seat belt use [31]. Airbags, however, are also designed to work in set parameters, usually based on a 50^{th} percentile male in the nominal seat position. This creates a risk for those who are on the extremes like a 5^{th} percentile female, where an airbag can cause injury [30]. There will also be a similar risk in autonomy, when drivers may choose to move outside of the nominal position to relax, sleep or undertake NDRTs.

NDRTs will also introduce more items being brought to the vehicle to occupy the passengers. Previous studies have highlighted how people use these items for example resting their phone on the steering wheel [5]. This can turn into a projectile when the airbag in the steering wheel deploys, leading to serious injury. Modern safety systems are likely to remain as OEMs transition to autonomy, and the fundamental passive safety systems like airbags and seat belts will remain. It is recommended that researchers consider the impact of airbags when designing studies and sharing results, as it could have a major effect on user experience and comfort.

3.5 Item stowage

Securely stowing items in the cockpit, although not legislated, is usually self-regulated internally. Door pockets, cup holders and gloveboxes are all designed to retain the objects in a crash. It is known that loose items can cause serious harm in even low speed accidents [32]. With increase in autonomy, and NDRTs there will be an increase in items brought to the vehicle to be used. This risk can be mitigated, however. There could be dedicated shoe stowage for sleeping and relaxing, as well as easy to access pockets for stowing heavy items in a handover scenario.

There could also be ways to reduce the need to use loose items in the car. For example, if the vehicle interior is designed intuitively, and with these needs in mind the occupant will not need to use a device to watch a movie as the vehicle can provide for that need more safely. This could be achieved by having a suitable display in front of the driver and passengers. If the vehicle can meet the needs of the user more effectively than a device, the occupant will be more inclined to use the built-in system.

4 Factor Hierarchy

The factors already discussed (seat positioning, airbag location, motion sickness, handover of control etc) are not equally important and some factors are more important than others. For example, it could be argued that airbag constraints are more important than the effect of mental loading. Although all factors influence the comfort and journey experience, prioritization is needed when considering the interior design concept. A proposal hierarchy is illustrated in figure 3.

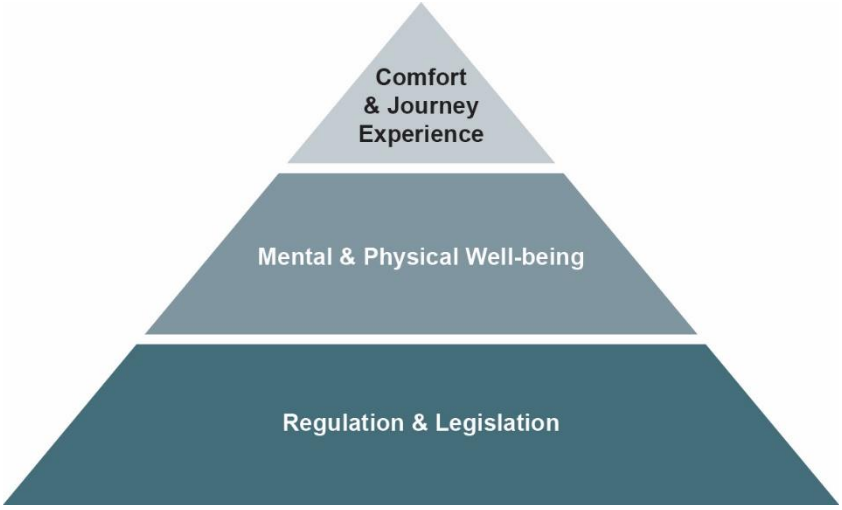

Fig. 3. Factor hierarchy triangle.

5 Design Recommendations

There are a series of evidence-based recommendations that can be made that relate to occupant safety, well-being and handover of control. All of these have an impact on either reducing discomfort or increasing comfort and so should be considered for future studies.

1) Display location should be positioned high up to allow the occupants peripheral vision to be on the outside world. This can be done by increasing the DLO (Day Light Opening) or raising the position of the display. The field of view should be roughly 15° for the display. This is to reduce the likelihood of motion sickness.

2) Seats should be limited to minimal rotation to reduce the likelihood of serious injury and motion sickness. Up to 10° rotation has shown no significant increase in motion sickness [26]

3) It should be assumed that seat belts are built into the seat to allow a greater level of movement. Although this could increase potentially discomfort and could impede on a NDRT; the seat belt is a vital safety component for autonomous vehicles.

4) Stowage of items used during NDRTs should be a priority of both researchers and industry to help increase time to situational awareness and increase mental well-being during HoC scenarios.

5) Use of items during NDRTs should not be placed between the occupant and the instrument panel (or airbag location) as this could lead to serious injury in the event of a crash. Instead consider how the vehicle can provide these needs.

6) Researchers and industry should consider the effect of situational awareness as a key factor when determining the ergonomics and user experience of the vehicle concept. A reduction in situational awareness increases the likelihood of an accident during handover of control.

Finally, it is important that the relationship each factor has on each component should be considered. Figure 4 shows the complex relationships that exist when designing interior concepts, particularly with regards to seat position, handover of control and situational awareness.

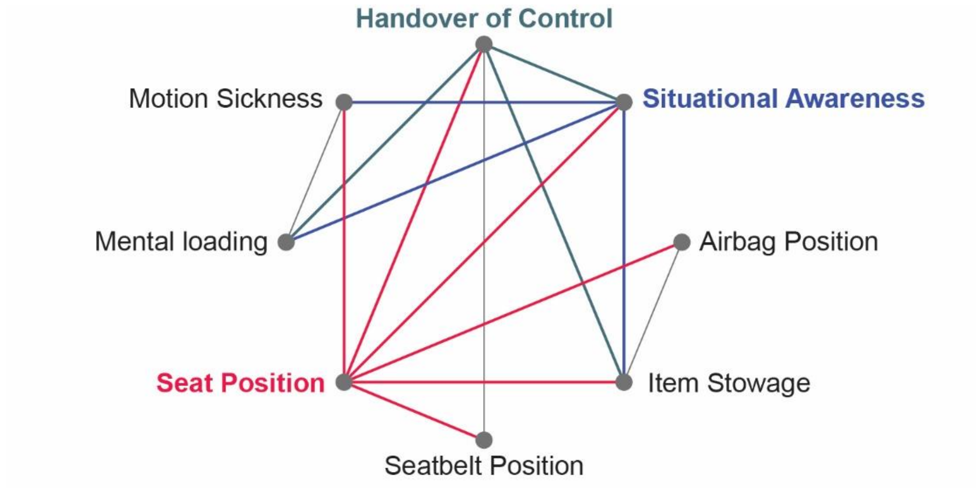

Fig. 4. Diagram showing the relationship between each design factor.

6 Conclusion

Autonomous vehicles have the potential to provide increased levels of comfort, through the ability to adjust seating position more frequently and become mentally and physically disengaged from the driving task. This paper presents a series of design recommendations for future studies to consider when investigating NDRTs. Physical wellbeing, passive safety and handover of control have been identified as important considerations that all researchers should consider but other topics including trust, ease of use and privacy. Future work will investigate the nuanced and complex needs of users to fully understand the holistic human factors requirements.

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