Towards a Data-Informed-Design (D-I-D) Framework for Autonomous Vehicle Design

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Abstract. Autonomous Vehicles (AV) have the potential to positively contribute towards a safer, greener, and more sustainable mobility. Yet, amongst the public, there is also a general sense of distrust and apprehension with regards to autonomous technology compromising AV acceptance and uptake. This paper introduces first steps towards the development of a Data-Informed-Design (D-I-D) framework for AV design with the aim to provide design practitioners tangible, relatable anchors to direct activities towards critical AV design features to ensure prospective passengers' needs and motivations, such as the need for safety and security, are met. A series of interviews were conducted with senior designers to identify key design features. The interviews revealed themes rather than individual design features, such as the need for 'comfort', which hint at the complex interactions between people's needs and motivations and how design can and should respond to this complexity. The results are discussed in the context of the further development of the D-I-D framework and future methods.

Keywords: Autonomous Vehicles, Design process, Vehicle Design, Safety Perception, Public Acceptance

1 Introduction

In this paper we present the results of a second in a series of studies into the development of a Data-Informed-Design (D-I-D) framework to support the design of future Autonomous Vehicles (AVs). The ultimate aim is to i) provide design practitioners tangible, relatable anchors to direct activities towards critical design features, and ii) enable design management to introduce more objectivity in their decision making.

The D-I-D approach is in part motivated by current design practice which heavily depends on designers' tacit knowledge.

Data-Informed-Design can be distinguished from Data-Driven-Design in which data is paramount, a primary input and at the centre of design decisions and suitable for engineering design where requirements can be defined explicitly. In contrast, the D-I-D approach assumes that the design team uses data to inform their decisions and used as one of many references, including design intuition, creative expression and qualitative feedback. The aim of D-I-D is to enhance design practices by helping designers to make mindful decisions and empower their creativity instead of confronting it and intended to enhance design efficiency and effectiveness by sizing or shaping the design space [1,2,3].

We here focus on a particular application area in which the D-I-D approach is expected to provide considerable value, i.e. the design of future AVs and their perceived safety, arguably the most critical aspect for their public acceptance [4] and subsequent socio-economic and environmental benefits they may bring [5].

Highly automated (SAE level 4) vehicles no longer require people to be in control of the vehicle and allow them to watch a movie, socialise, or simply relax during their travels. This asks for a radically different design strategy moving away from today's driver-centric design approach to an entirely passenger-centric focus [6]. A key consideration for this passenger focussed design era is the general sense of distrust and apprehension with regards to autonomous vehicle technology amongst prospective customers [4], a concern of particular concern during the introductory phases. This subsequently led us to ask the question what design features are of particular importance in instilling a sense of safety on behalf of future customers?[1].

Whilst this may be relatively well understood for conventional vehicles (e.g. elevated seating position, high belt line), AVs introduce a new set

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[1] Note that the public here refers to both prospective AV passengers as well as bystanders, i.e. (vulnerable) road users interacting with such vehicles.

of challenges with people's concerns only partially understood [6,7]. Furthermore, given that AVs are an emerging technology and only experienced by the public at a demonstrator or concept vehicle level, designers lack feedback with regards to real-world interactions with such vehicles and the ability to compare alternative design directions. Subsequently, this creates an *informational asymmetry* between designers and prospective AV customers.

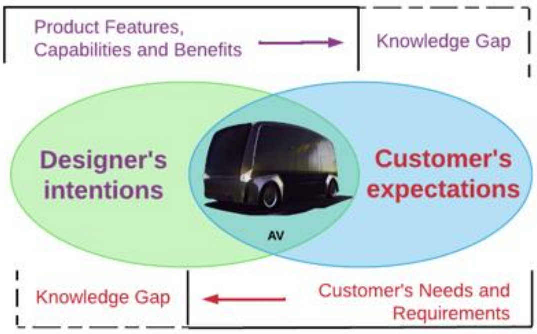

Fig. 1. Knowledge gap and information asymmetry in the design of future autonomous vehicles (after [1]).

Based on the idea of the design process as a communication model [8,9], the designer is assumed to play the role of a communicator creating a range of forms (e.g., design features) and develop a relationship with the customer as part of the communication process (see Figure 1). However, designers may have an incomplete understanding of prospective AV customers' needs and requirements, while AV features and characteristics designed to fulfil assumed needs and requirements may not be perceived or appreciated by prospective AV passengers. In turn, this *information asymmetry* leads to a *knowledge gap* on behalf of both parties with a potential breakdown in communications [8,9] which, in the current context, may result in low acceptance and uptake of AVs. The D-I-D approach attempts to bridge this gap by creating data and knowledge to assist designers in (explicitly or implicitly) making informed creative decisions that positively address, in this case, concerns around safety of AVs.

To this end we recently conducted a study in which we interviewed senior automotive and transport designers about their understanding of the role the exterior vehicle design and in particular specific vehicle design features that may instil a sense of safety on behalf of the passenger and bystander, i.e. pedestrians and cyclists [2]. The study revealed a common understanding of key features but also an apparent dichotomy or incompatibility in terms of design directions when considering passengers versus bystanders. Figure 2 provides one such example: whilst a higher belt line (left image) was considered to enhance a passenger's sense of safety, a pedestrian may feel safer when confronted with a less robust looking AV featuring a lower belt line (right image). Furthermore, the designers indicated that their understanding was largely based on their experience of conventional vehicles leading to uncertainty as to the validity in the context of future AVs, reflecting the aforementioned knowledge gap.

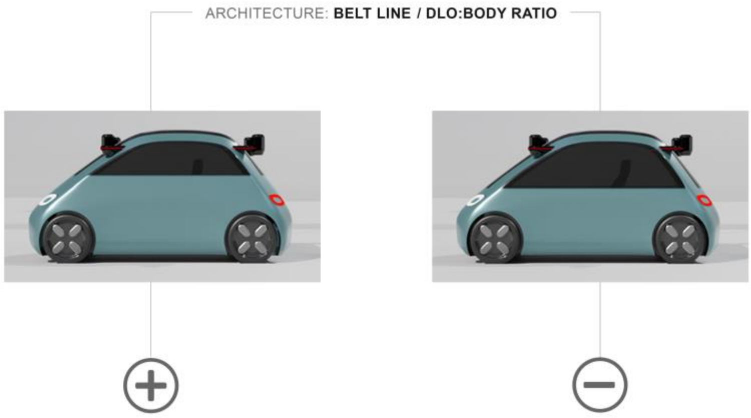

Fig. 2. Knowledge gap and information asymmetry in the design of future autonomous vehicles (illustrations by Yichen Shu)

The aim of the current study was to build on the previous study and expand beyond the exterior design features by focusing on interior and User Interaction (UI) design features instead. We conducted a series of semi-structured interviews with senior automotive and transport designers and educators to develop an initial list of interior and UI design features deemed to be relevant in the context of future AV passengers. Similar to the previous study, we constrained the investigation to a specific AV typology and context. Specifically, the type of AV referred to in this study constituted a shared vehicle managed by a mobility service provider; SAE level 4 automation; no vehicle controls; small footprint 2-seater; forward facing seating arrangement; urban use in mixed traffic conditions; geofenced area of operation and driving at a maximum speed of 30mph.

2 Methods

2.1 Recruitment

Invitation letters were sent to five senior automotive and transport designers with 10 plus years of experience in industry. They were asked to partake in a short 30-minute interview and informed that the interview would be audio-recorded and that personal data would be treated anonymously with verbal consent requested on the day of the interview. Interviewees were not offered any financial compensation for partaking in the study.

2.2 Interviewing procedure and analysis

The interviews were semi-structured and based on a predefined protocol that consisted of open-ended questions to explore what design features were considered to be important in the perception of safety and trustworthiness of AV interiors. Acknowledging the wide variety in AVs including automation level, vehicle size, seating arrangement, and context of use, for the purposes of this study the interviewees were first provided a short description of the type of AV to consider (see above).

Table 1. Hierarchy of interior vehicle design

Level	Design features
Architecture	**Cabin** Windows, Roof, Transparency, Height, Width
Form	**Furniture** Seating- form/proximity/height/position, seating direction, privacy features, Controls, interior layout, storage space
Detail	Colour, Materials, Finish, Seatbelts, Lighting, Sound, Design Language, Biometric Monitoring
Communication	Info display, Commands, Override/ Changing course, Entertainment, Visible tech vs. Hidden tech, Haptic touchpoints, Passive vs. Active, Security measures

To assist interviewees in considering a range of design features, they were shown an adapted version of the hierarchy of vehicle design framework [10]. The framework was expanded by considering interior vehicle design features organised into four levels. The *Architecture* level refers to the cabin (size, structure, transparency), and the *Form* refers to the furniture (seating, direction of travel, interior layout, privacy features). *Detail* refers to colour, materials and finish as well as lighting, restraints and design language. Finally, *Communication* encompasses the method and display of information delivery, override/commands, proximity and type of controls, entertainment, and the visibility and passivity of technology.

Following the presentation of the framework, the interviewees were asked to discuss and expand on which design features they deemed most important in instilling the perception of safety and trustworthiness from the perspective of the AV passenger.

All interviews took place over a conference call facility (Zoom) with associated capabilities to share screens and show the hierarchy of vehicle design for reference. The interviews were recorded and transcribed using an automatic transcription software (Panopto). Transcripts were subsequently reviewed and corrected where needed. The data was analysed using the hierarchy of vehicle design framework. For brevity, in the next section, the results are summarised and discussed together.

3 Results and Discussion

3.1 General comments

The interior design interviews often began with a higher level discussion of what safety in interiors consists of, being more nuanced and multi-system than the hierarchy of design features may suggest. There was a discussion about whether the perception of safety needs to be consciously designed and constructed in an obvious visible manner, or whether safety ought to be designed in a more nuanced and intelligent way. There was also conversation on whether the interaction within an autonomous interior ought to be more passive as it is during an elevator ride, or more active in the way gamification of a vehicle interior might offer. The importance of the need for connection with the outside environment was highlighted, both visually through glazing, and digitally through the recognition and engagement with passing structures or services. Lastly, a distinction was made between the concept of feeling safe *in* the car, versus feeling safe *from* the car as an approach to thinking about interior safety in autonomous vehicles.

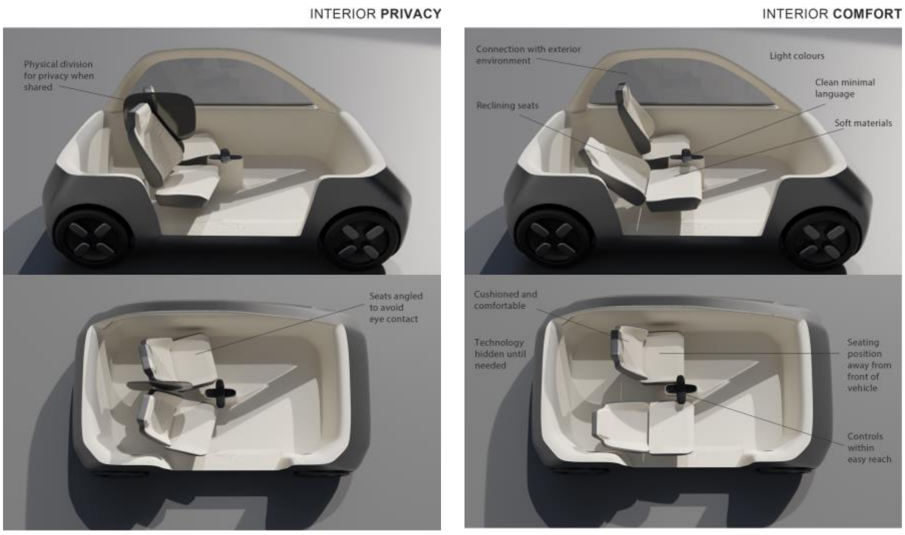

Fig. 3. Illustrations of a selection of interior design features considered to be of importance in instilling a sense of safety in AV passengers (illustrations by Yichen Shu).

3.2 Architecture

With regards to the design features at the architecture level, the following features were considered. Respondents were equally split as to the preference of more or less *glazing*, half stating that more glass equals more visibility and connection with the outside environment thus putting the passenger at ease, with the other half stating that less glass was preferable so that passengers feel less exposed. One respondent also suggested a *panoramic roof* aids with better visibility and is in line with a more premium feel. No comments were made as to the *height* or *width* of the interior cabin.

3.3 Form

At the form level, most respondents agreed that forward *direction of travel* was preferred in an autonomous vehicle given that this is the preferred choice in environments like trains or buses where both are available, with one respondent suggesting non forward travel to be considered only in short journeys, and the consideration of flexible/rotating seating directions to avoid passengers being committed to one direction of travel only.

With regards to *seating*, it was considered that a higher *seating position* within the vehicle would help passengers feel more safe and less looked down upon by other drivers on the road, as well as the seating being situated away from the front of the vehicle being the first point of contact in a potential collision. Within the vehicle, respondents also mentioned angling seats away from each other so passengers could avoid eye contact in a car sharing scenario, thus maintaining a desired boundary and privacy from other passengers. In order to increase comfort, reclining seats were suggested by interviewees as preferable, with one mention of bench seating to allow passengers to sit closer together for instance in the case of parents and young children. It was also mentioned that considering the growing size of adults across the globe, it is necessary to offer more inclusive seating and to consider standing or perch options for shorter journeys or when passengers wish to remain at a distance from others.

With regards to *interior layout*, physical barriers for *privacy* in a shared environment with strangers was approved by respondents to help make passengers feel safe, and curating the interior layout to feel as spaced out as possible in a small footprint vehicle, especially with regards to having free space in front of the seating area was an important consideration.

3.4 Detail

With respect to details, there was a clear consensus on using lighter *colourways* to create a calm environment that appears more spacious, and help to reduce anxiety or panic associated with a lack of control in an autonomous driving situation. However, it was suggested that darker colours would be a better choice in a shared environment to better mask any accumulation of wear associated with more heavy-duty use.

In terms of *materials*, the consensus from respondents was to use materials to create a warm and comforting environment, with materials that are both durable and easy to clean of particular importance.

With regards to *lighting*, the majority of respondents felt that mood lighting that was changeable would help passengers feel more relaxed and hence safer. On the subject of *sound*, it was felt that soundproofing the vehicle would help to eliminate unexpected noises that are a normal part of a journey when in control of driving and witnessing the contributing factors. Having a soundtrack of the passenger's choice would also contribute to the careful creation of a *personalised environment* even before entering the vehicle which was mentioned often by interviewees.

The topic of *restraints* were supported by the majority of interviewees, with support for seat belts initiated by the view that they are a psychologically ingrained part of the experience of being in a vehicle that contributes to passengers feeling safe, as well as an importance for travelling with younger children.

Respondents were in favour of *biometric monitoring* for the purpose of the vehicle being able to respond to the passengers changing physiological parameters by consequently changing the speed of the vehicle, or introducing changes in lighting, smell, or sound to reduce anxiety for the passenger. Related to this topic, it was suggested that *motion sickness* would need to be addressed to improve the journey experience and feeling of safety in a small footprint vehicle.

In terms of *design language,* no clear consensus was presented, however respondents mentioned that a clean and minimal language would be preferred, avoiding harsh or utilitarian themes, with one respondent viewing a premium offering to be essential to improving uptake and use of a small footprint autonomous service. There was consensus however on the theme of 'comfort' being a clear suggested direction in creating a sanctuary feel for the interior.

3.5 Communication

By far the communication section of the framework dominated the bulk of interview discussions, with a consensus amongst interviewees that the information system was the most important parameter in assisting the feeling of safety for passengers. With regards to the overall communication of *information*, all respondents suggested a 'status update' method of communication where information is constantly displayed with relation to the health of the vehicle and the status of the journey. This was suggested as important in keeping the passenger up to date and reassured, with the method of delivery suggested as a continuous passively running but subtle visual update that could be turned off if desired, as well as concurrent but intermittent audio updates, bearing in mind to ensure updates are inclusive to passengers with disabilities.

With respect to *commands*, it was universally agreed that the presence of a clearly visible emergency button is needed to assure passengers that in the event of needing to immediately curtail the journey due to health or emergency reasons that they would have the control to do so. It was also agreed that all controls the passenger may have access to for configuring the interior environment should be within easy reach of the seated and restrained passenger.

The topic of *technology* generated discussion on what would be most appropriate for the autonomous experience as a whole, with the majority of respondents deeming a lighter touch, with more intuitive technology that remained hidden until needed to be the best way forward. A few respondents also felt that in the absence of customising the interior environment for comfort there isn't the need for extra technology to be added to the interior and imagined a future where passengers bring their own technology with them that plugs into the vehicle. With respect to screens, some interviewees felt that the absence of screens altogether was best, instead with technology embedded into surfaces, whilst the remainder agreed that screens should be kept to a minimum and of a smaller size where possible. The importance of haptic controls for important operations like stop/start or the opening of doors was highlighted, but digital controls were recommended for everything else, and a suggestion for movable controls was also put forward to aid ergonomic efficiency whilst seated.

With regards to *security*, camera monitoring was suggested by multiple respondents as a necessity to improve the feeling of safety in a shared vehicle as well as to aid in the ability to relax, which is no different from current transport modalities like taxis, buses or trains. The desire to create a system where the passenger has access to a human being at the touch of a button to assist with emergencies or queries was suggested, as well as humanising audio voices to create a less machine oriented and more personal environment of safety. It was also felt that rides should be able to be shared with a friend remotely to aid in feeling safe when travelling in a shared scenario.

Lastly, the topic of *entertainment* was an important one amongst interviewees with ideas such as a digital concierge, to a personally curated environment suggested to aid in distraction and hence relaxation and a subsequent feeling of safety. It was suggested that time well spent is a currency in the world of automation, and enabling the passenger to choose activities that are rewarding or pleasurable helps to overcome the hesitation of use of such a service. The importance of creating a new level of experience with incentives that aren't available when a passenger is in control of a car, possibly with the earning and redeeming of points that can be exchanged in a retail setting for example as a reward for supporting a more sustainable mode of transport were also suggested.

4 Conclusions and future research

In this paper we have attempted to identify interior vehicle and UI design features that may instil a sense of safety in future AV passengers as part of a wider Data-Informed-Design (D-I-D) framework for AV design. To this end, senior automotive and transport designers and educators were interviewed. The majority of consensus was found within the realm of technology and security as a means to increasing the perception of safety for passengers in a small footprint vehicle.

Themes, rather than individual design features emerged such as the need for ‘comfort’ as a design direction for the interior, the concept of creating added value and experience through entertainment, added luxuries not possible whilst driving, and the curation and customisation of the interior. The importance of linking the vehicle to its outside environment physically as well as digitally was also an outcome and area to be further explored.

Interesting areas for future development as a consequence of this research includes the opportunity to develop a subtle visual language for safety that extends beyond the more expected use of text, audio or icons, and exploring the narrative and experience philosophy of an autonomous interior with gamification and enhanced or unexpected levels of interaction not previously possible.

Together with the previous study into exterior design features [2], our work provides a starting point for the development of the D-I-D framework for the design of future AVs. However, the current findings also hint at potentially complex interactions between people's needs and motivations and how design can and should respond to this complexity (see also [6]). Previous research into the role of human needs and motivations in the context of the acceptance of AVs have identified the need for safety and security, competence, autonomy, stimulation, and the need for meaning as key factors [7,11]. Whilst the prioritisation and focus on safety and security in our work to date seems justifiable and has been informative, the suggested impact of the wider passenger experience (e.g. comfort, entertainment) on people's perceptions of safety point towards the need to adapt a more holistic and less compartmentalised approach as these themes or design features bear relevance beyond safety and across the various needs and motivations. The intention of our upcoming research is to explore if and to what extend this indeed may be the case and understand the implications for current and future methods.

Thus far we have explored one side of the communication model, the designers' perspective. Next, the visualisation of these perspectives, akin to the example provided in figure 2, allows us to evaluate the knowledge gap on behalf of the customer (AV passenger). In other words, are the safety relevant design features appreciated as expected by the designers. In addition to interviews and focus groups, our research will explore the Best Worst Scaling (BWS) method, a quantitative choice-based technique used for understanding respondents' relative valuation of different design features [12]. Such studies are expected to allow us to better understand which design features (or design themes) of an AV play the most significant role in customers' perception of safety and beyond.

Finally, the research will aim to understand the value, barriers and enablers for the integration and acceptance of research and Data-Informed-Design in both commercial design practice and design education. Within the automotive and mobility industry, communication between departments (e.g. design, research, engineering) is often limited for practical and cultural reasons leading to suboptimal strategic, fundamental design decisions. To date, the understanding of the role of data in examining future design solutions is at a rudimentary stage with few theories and even fewer frameworks. Interpreting data into design strategies for human benefit demands data literate designers and, conversely, design literate researchers.

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