Designing Perceived Safety in Autonomous Vehicles

A Data-Informed-Design Approach Sizing and Shaping the Design Space

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ABSTRACT

The perceived safety of Autonomous Vehicles (AV) is considered a major challenge towards their public acceptance. Here we explore the role of vehicle design in instilling a sense of safety on behalf of prospective passengers. Previous work showed that variations in exterior design affect people's perceptions although the particular design features driving these shifts in perception were not elaborated on. We aim to identify and validate the relative importance of design features pertaining not just to the vehicle exterior. The work contributes towards the development of a wider Data-Informed-Design (D-I-D) approach to assist designers to make mindful decisions, empower their creativity, and increase design efficiency and effectiveness by sizing or shaping the design space. Based on a series of semi-structured interviews with senior designers, we developed an initial taxonomy of design features. Their relative importance was subsequently validated in a forced-choice experiment in which a panel was asked to judge perceived safety of concept autonomous vehicles including particular design features. Preliminary results indicated that not all features had the intended effect suggestive of a "knowledge gap" on behalf of the designers indicating the potential benefits of a Data-Informed-Design approach.

CCS CONCEPTS

• **Human-centered computing - Interaction design - Interaction design process and methods - User centered design**; • **General and reference Cross-computing tools and techniques - Design**; • **Applied computing - Law, social and behavioral sciences - Psychology**;

KEYWORDS

Data-Informed-Design, Autonomous vehicles, Advanced design process, Perceived safety, Public acceptance

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1 INTRODUCTION

In just over a Century, we have witnessed the transition from horse-drawn carriages, to automobiles, to AI-driven carriages, better known as Automated Vehicles (AV) (see Fig 1). Highly automated vehicles (SAE level 4) no longer require people to be in control of the vehicle and allow them to watch a movie, socialize, 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 [1].

A key consideration for this passenger focused design era is the general sense of distrust and apprehension with regards to autonomous vehicle technology amongst prospective customers [2], 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? The importance of designing for perceived safety becomes apparent considering frequently observed discrepancies between perceived and actual safety [3]. Similar to roundabouts being perceived as dangerous by drivers despite their positive impact on traffic accidents [4], the public may still perceive AVs as unsafe despite impeccable future safety records. Subsequently, perceived safety has been conceived of as people's feeling of reassurance and perceived risk without considering standards or safety history [5, 6].

In response to this challenge, significant efforts are underway to comprehend and enhance the way people perceive safety in their interactions with future AVs [7]. Most of these endeavors primarily concentrate on designing discrete, often digital, and display-based vehicle interactions, exploring various input and output methods, and the application of concepts such as system transparency, anthropomorphism, customization, and personality [8]. In contrast, the aspect of designing the vehicle's exterior and its role in shaping the perception of safety remains largely unexplored. This is despite the fact that the vehicle itself serves as the tangible representation and

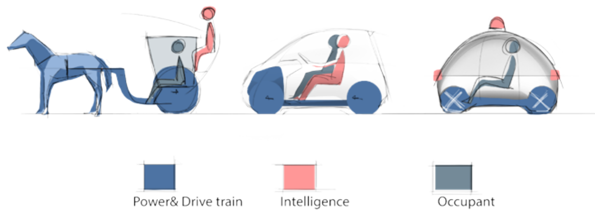

Figure 1: From horse drawn carriages to automobiles to AI-driven carriages

embodiment of Artificial Intelligence (AI) and, as such, serves as the primary interface that establishes the initial relationship between people and AVs. We therefore conceive the vehicle, encompassing both its interior and exterior, as a fundamental component of the interface through which future passengers will engage with AVs. The physical presence of the vehicle, its overall impression, shape, form, color, material characteristics, will significantly influence the perception of safety and the overall experience of AVs. Indeed, in the field of social robotics, design features such as the shape and size of a robot have been found to affect people's safety perception [9].

It is well-known that the appearance of products affects consumers' choices by conveying aesthetic, symbolic, functional, and ergonomic information as well as drawing attention to the product itself and enabling customers to categorize it [10]. Regarding vehicle design specifically, aesthetic appeal and distinct design features are the primary drivers of customer awareness of vehicles' properties and traits. Vehicle designers convey design features (e.g., premiumness, durability, sportiness) in an attempt to shape customers' perception of the future vehicle [11]. Furthermore, the aesthetic perception of a vehicle's exterior is consistently reported to be amongst the top vehicle purchasing reasons [12]. In the context of future AVs, however, our understanding of the role of design, and the extent to which conventional vehicle design knowledge can be extrapolated, is far less well understood and under researched. A rare exception is a study by [13] in which a series of autonomous shuttles were visually evaluated. As expected, variations in exterior design affected people's perception of safety. However, the particular design features driving these shifts in perception were not elaborated on and, to date, a systematic and validated taxonomy of design features related to the perception of safety in AVs is not available. In part, this research is aimed at addressing this gap.

Current design practice heavily depends on designers' tacit knowledge. While this of course can lead to successful designs, specific and validated knowledge about the impact of certain design features early in the design process may prove valuable to designers, in particular for new product categories such as AVs. In the current example of perceived safety, designers may have a fairly good grasp of the relative importance of design features in conventional vehicles (e.g. elevated seating position, high belt line). However, AVs introduce a new set of challenges with people's concerns only partially understood [1, 8]. 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. We refer to this situation as an informational asymmetry between designers and prospective AV customers.

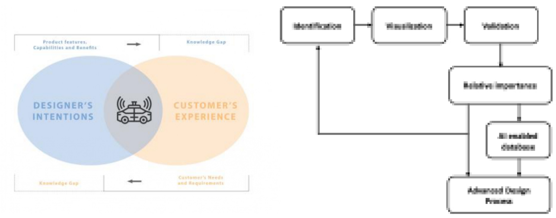

Figure 2: Left: Knowledge gap and information asymmetry in the design of future autonomous vehicles (after [16]). Right: Development stages of the Data-Informed-Design framework

Based on the idea of the design process as a communication model [14, 15], 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 2 left). However, designers may have an incomplete understanding of prospective AV customers' needs and requirements, while on the other hand, 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 comprises a knowledge gap both for the designer and prospective passenger and may lead to a potential breakdown in communications [14, 15] which, in the current context, may result in low acceptance and uptake of AVs.

1.1 Data-Informed-Design (D-I-D)

To bridge this gap, we are developing a Data Informed Design (D-I-D) to enhance the design process by incorporating data that informs the designer if and to what extent certain design features have the intended effect on customer perceptions and experiences. The intention is to assist designers in making informed creative decisions that positively address, in this case, concerns around the perceived safety of AVs.

Traditionally, car designers have heavily depended on study data and customer insights provided by marketing departments to understand consumer expectations. However, the process of creating and collecting this data often remains a 'black box'. Furthermore, this data is frequently disconnected from the practical context of car design. This disconnect may arise from the study design, which often lacks design stimuli, or from participants being unable to clearly articulate their preferences and reasons for favoring certain designs. While marketing teams often evaluate specific customer attitudes, conduct surveys, and summarize results, the quality and relevance of this information can be questionable.

In D-I-D, the role of the designer is transforming into that of a co-creator. D-I-D utilizes data and analytics of perceived attribute characteristics (e.g. perceived safety) to steer the design process.

Its main objective is to improve the design process, elevate the quality of designs, and ensure that they align closely with the needs, behaviors, and attitudes of customers and other stakeholders. This approach enables designers to make more informed decisions, minimizes the need for trial and error, and boosts the overall efficiency of the design process.

D-I-D can be distinguished from Data-Driven-Design in which data is paramount, a primary input and at the center 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 design decisions and empower their creativity instead of confronting it and intended to enhance design efficiency and effectiveness by sizing or shaping the design space [16–18].

The development of the D-I-D approach involves of a series of iterative activities as shown in figure 2 (right). The identification phase is aimed at finding design features deemed relevant by designers and prospective AV users to instill a sense of safety. In the subsequent visualization phase, these design features are incorporated into AV "exemplars" which are then rated by a sample of prospective AV users to understand if, and to what extent, the design features have the intended effect (validation). In turn, the resulting data, i.e. the relative importance of the different design features, can be used to inform the advanced design process. Over time, it is the ambition to develop high quality labelled data sets and AI tools to explore the possibility of judging proposed designs along perceived attribute characteristics and provide near instant feedback to inform the advanced design process.

In this paper we present the results of the identification, visualization, and validation stages in the development of the D-I-D framework and explore if and to what extent the identified design features were indeed seen to affect prospective AV passengers' sense of safety. Based on the obtained results, we will reflect on the D-I-D approach and identify challenges and opportunities as well as directions for future research. In the following we will first set out the methods of these stages in more detail.

2 METHODS

2.1 Exterior Vehicle Design Features

To identify AV design features hypothesized to be important for the perception of safety in AVs, 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 instill a sense of safety on behalf of the passenger and bystander, i.e. pedestrians and cyclists [17]. An overview of the exterior vehicle design features is provided in Table 1 and organized along the hierarchy of vehicle design framework [19] which sets out fundamental levels of design features of exterior vehicle design (vehicle architecture, form, details).

Regarding exterior design features, key words that were referred to in relation to passengers' safety perception across the design experts included the need for AVs to appear stable, strong, confident, planted, solid, and balanced. However, when considered from the perspective of a bystander (such as pedestrians or cyclists), these design directions were considered to potentially have the exact opposite effect (i.e. feeling less safe), thus creating a tension, or trade-off, between designing for safety for the passenger versus bystander. For example, whilst a higher belt line 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. This was considered a design challenge not well understood.

Furthermore, by their own admission, the designers commented that although they were confident about design features for conventional vehicles, they were less certain about their validity in the context of future AVs, reflecting the aforementioned knowledge gap. The designers further stated that their understanding was untested, indicating the potential benefit D-I-D approach may provide.

2.2 Visualizations

The second step in the development of the D-I-D framework is the visualization of the identified design features. Note that throughout the different stages we constrained our investigation to a specific AV typology and context. Specifically, we focused on a small footprint two-seater, shared automated (level 4) vehicle. The vehicle would not include any vehicle controls, have a forward-facing seating arrangement, and be used in urban mixed-traffic conditions at a maximum speed of 30mph (48kph) in geofenced areas.

As a proof-of-concept study, we implemented only a selection of exterior design features in a relatively conventional looking reference vehicle, or "exemplar". Note that to facilitate interpretation of the design features, a conventional design was used as a reference as opposed to a more novel, atypical vehicle design enabled by vehicle automation. In addition, the vehicles were presented in an urban environment with manikins placed both in and outside the vehicle to illustrate scale. Figure 3 shows the visualizations of six design features as identified by the design experts. For comparison purposes, the baseline vehicle is here shown in the left column with the visualization of the vehicle containing single design features identified by the design experts shown on the right. With reference to the visualizations, increased wheel size, vehicle size and width, A-pillar width, visibility of AV technology, and full width lighting, were all hypothesized to positively affect prospective AV passengers' safety perceptions. These design features of interest were highlighted in annotated versions to ease detection as shown in figure 3.

2.3 Validation

For the validation of the exterior design features, a forced-choice study was conducted with two panels of 9 participants each (total n=18, 13 female; 5 male; age range 22-28 years old) consisting of undergraduate and postgraduate students across a range of departments from Hong Kong Polytechnic University. Following an introduction to the concept of vehicle automation and the particular scenario we focused on (see section 2.1), the panels were shown each of the six image pairs (see figure 3) in random order three times, i.e. participants were asked to make eighteen comparisons in total.

Table 1: Exterior vehicle design features hypothesized to be associated with perceived safety of AVs [17]

Level	Design feature	
Architecture	Large wheels positioned in corners Strong sturdy cant rails & pillars	Larger vehicle size Wider vehicle width
Form	Stable solid overall form Geometric clean language	
Detail	Full width lights not too high Explicit visible AV tech Balancing visibility/exposure	

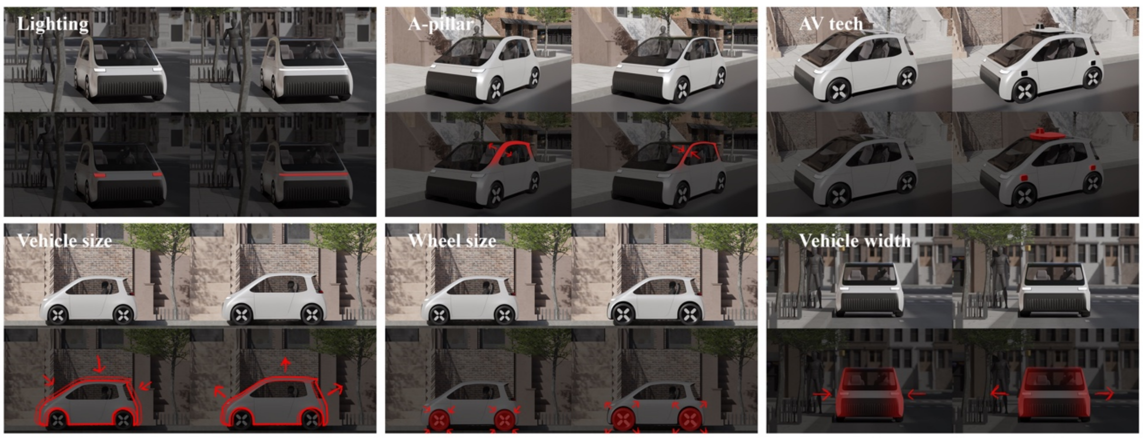

Figure 3: Visualizations of safety relevant exterior design features (right) compared to the reference vehicle (left); Bottom rows of annotated versions highlight the design features of interest.

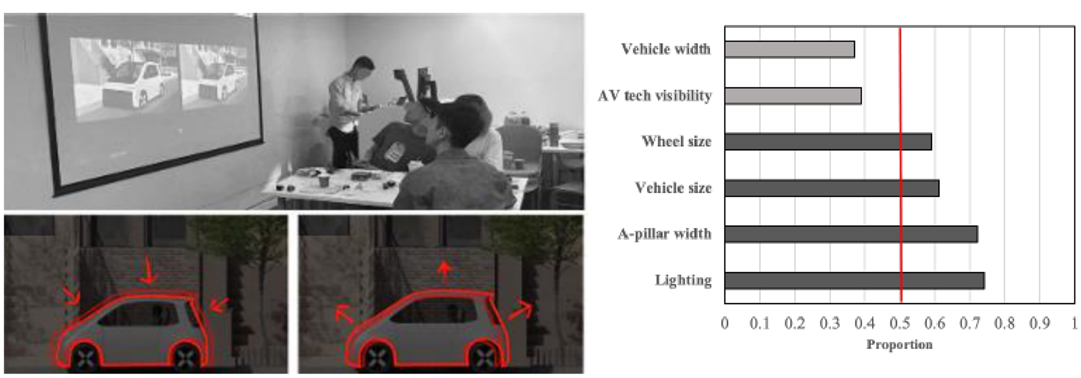

Figure 4: Left: Illustration of the forced-choice study set up (top); annotated image pair indicating a difference in vehicle size (bottom). Right: Relative importance of design features: features being perceived as less safe (<0.5), equally safe (0.5), and safer (>0.5) compared to the reference vehicle

The images were projected in a seminar room with participants asked to indicate on a score sheet in which of the two vehicles (left vs. right) they would feel safer in (see fig 4 top left). During the pilot phase it became apparent that some people struggled to spot the differences between the vehicles in each pair. In response, annotated versions were created highlighting the design features of interest. Figure 4 (bottom left) shows an example related to vehicle size.

The panel would see the original image pair for 20 seconds followed by the annotated version for a further 10 seconds before reverting to the original image for 30 seconds after which participants were asked to provide their choice. The total exposure duration to each pair of vehicles was 1 minute after which the next pair would be displayed. In total, each panel evaluation took approximately 45 minutes to complete. The data was analyzed by comparing the number of times (proportion) the vehicles including the particular design feature was rated as safer.

3 RESULTS AND DISCUSSION

Figure 4 (right) shows the results of the forced choice study. It indicates, in descending order of importance, the design features that had most impact on people's perception of safety, i.e. their relative importance. Values greater than 0.5 indicate the design features to a have a positive impact, while values smaller than 0.5 indicating the design features to have no or the opposite effect, i.e. being perceived as less safe. It can be seen that four of the identified features (i.e. vehicle and wheel size, lighting, and robustness of A-pillars) had the intended effect on safety perceptions, while the remaining features (AV tech visibility, vehicle width) failed to do so.

At first glance, these findings suggest that the designers have a fairly good idea as to what design features may affect people's sense of safety in AVs with four out of six features showing a positive contribution. On the other hand, the results would also suggest the existence of a knowledge gap. Two of the design features failed to impact safety perception or were even perceived to be detrimental (< 0.5). Design features thought to be important by designers are not necessarily being perceived as important by the public. As such, these findings demonstrate the potential value of the D-I-D approach.

However, it should be noted that the results of this proof-of-concept study should be interpreted with care as there are several methodological uncertainties. First, we manipulated local design features in otherwise unaltered designs assuming such "independent" design alterations to be valid for the holistic or global vehicle evaluation [20]. Further, image fidelity and realism may impact people's perceptions as well as the chosen viewing angles and the context or environment in which the vehicles were presented. To understand the most appropriate and valid visualization methods further research will be required. Finally, the study was based on a small and biased sample size and future research would benefit from larger and stratified samples to obtain more robust and insightful data. In particular, we are suggesting to use of the Best Worst Scaling (BWS) method, a quantitative choice-based technique used for understanding respondents' relative valuation of different design features at scale [21]. Using an online platform with hundreds of respondents visually evaluating different designs, the resulting data is expected to allow us to better understand and validate which AV design features play the most significant role in customers' perception of safety and beyond.

Finally, future 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) can be 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 within this industry is limited. Interpreting data into design strategies for people's benefit demands data literate designers and, conversely, design literate researchers.

4 CONCLUSIONS

In this paper we have made an attempt to uncover and evaluate the impact of exterior vehicle design features in instilling a sense of safety in future AV passengers within the framework of Data-Informed-Design (D-I-D). The aim of D-I-D is to enhance design practices by helping designers to make mindful design decisions and empower their creativity intended to enhance design efficiency and effectiveness by sizing or shaping the design space. The findings showed that this approach indeed has the ability to identify their relative importance and inform the advanced design process.

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