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INTRODUCTION

SUSTAINABLE DEVELOPMENT

SOCIAL INNOVATION

TECHNOLOGY APPLICATIONS

HEALTHCARE AND WELLNESS

POLICY AND GOVERNANCE

ALTERNATIVE FUTURES

MADE IN...

Enhancing User Experience in Autonomous Driving Levels 4 and Above: A Novel Seat Concept for Motion Sickness Mitigation.

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Abstract

The rapid advancement of technology, particularly in autonomous driving, has brought about a profound transformation in the automotive industry. This paper introduces a research-driven strategy aimed at tackling emerging challenges related to non-driving activities in autonomous vehicles, with a specific focus on mitigating motion sickness. Recognizing the growing prevalence of light usage in the cockpit and the expected rise in non-driving engagements, this study underscores the urgent necessity for innovative solutions. Through comprehensive research on future mobility trends, levels of driving automation, and user experiences, this paper proposes a novel automotive seat concept tailored to alleviate motion sickness arising from increased non-driving activities in autonomous vehicles.

The proposed seat design features a wrap-around structure to facilitate enhanced privacy and flexibility in both personal and group activities. A key component of this solution is the Anti-motion Sickness Light Warning System, strategically integrated into the seat's backrest. Leveraging ISELED technology, this system offers real-time synchronization with autonomous driving systems, issuing light warnings to passengers prior to unexpected movements, thereby minimizing the likelihood of motion sickness. While demonstrating promising outcomes, the paper acknowledges certain limitations. These include the necessity for further exploration of interactive elements within the seat design, research to exploit the potential of advanced lighting effects using ISELED technology and ergonomic considerations for the seat itself. By shedding light on the impact of autonomous driving on user experiences, this study contributes to the ongoing discourse and underscores the pivotal role of technology in shaping the future of automotive design.

Introduction

In recent years, vehicle interior lighting has undergone significant advancements owing to rapid technological progress and evolving user preferences. The 2022 Mercedes-Benz EQS integrates innovative lighting solutions throughout its interior. With up to 13 strategically positioned functional lights (see Figure 1), this model not only enriches the driving and passenger experience but also underscores the pivotal role of lighting in automotive design.

Currently, lighting design has shifted from being supplementary to essential within the cockpit, significantly enhancing the driving and passenger experience. This trajectory is expected to continue, with future automotive lighting applications becoming even more innovative and diverse.

Figure 1. Interior of Mercedes-Benz EQS 2022 (Drive, 2022)

Literature Review

The literature review of this paper primarily focuses on future mobility and cockpit design. It commences by examining future transportation scenarios and delves deeply into potential changes in cockpit configurations.

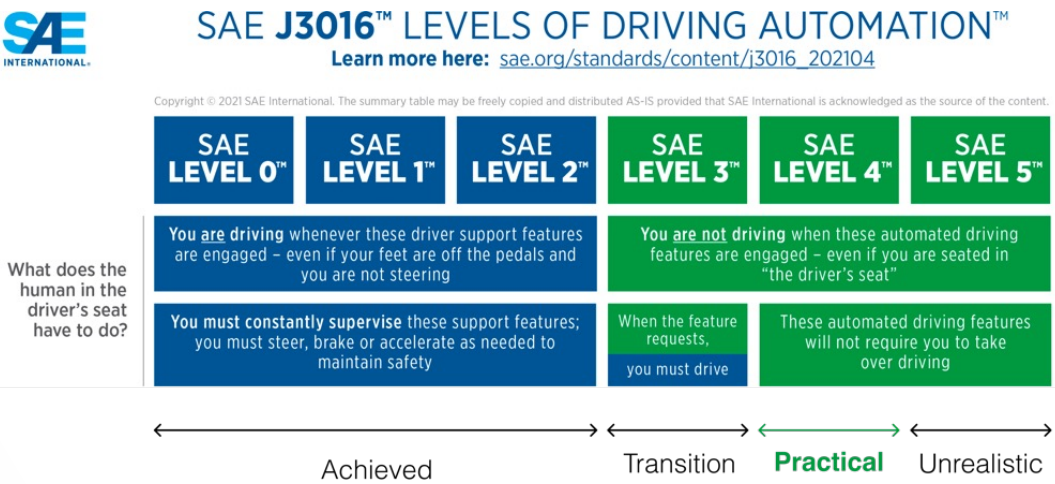
1. Future Mobility

The future of mobility will witness significant changes in the role of automobiles, particularly with the emergence of autonomous vehicles. The discussions are summarized in three main aspects: driving automation, new contexts, and new scenarios.

Driving Automation

Autonomous driving technology has witnessed rapid advancement, necessitating standardized taxonomy and definitions to classify the various levels of automation. Society of Automotive Engineers International has established a widely recognized standard with its classification of autonomous driving into five levels (SAE International, 2021).

Table 1. SAE J3016 Levels of Driving Automation (SAE International, 2021)



Through the comparison of various levels of autonomous driving technologies and assessing the current market adoption, the author contends that Levels 0 to 2 autonomous driving have nearly achieved widespread application in real-world scenarios. Even Level 3 autonomous driving, despite its capability to take over most driving tasks from human drivers, still requires human drivers to remain fully engaged in vehicle operation, presenting a technical challenge (see Table 1).

Table 2. Estimated passenger vehicles sold with autonomous-driving technologies installed, % (McKinsey, 2023)

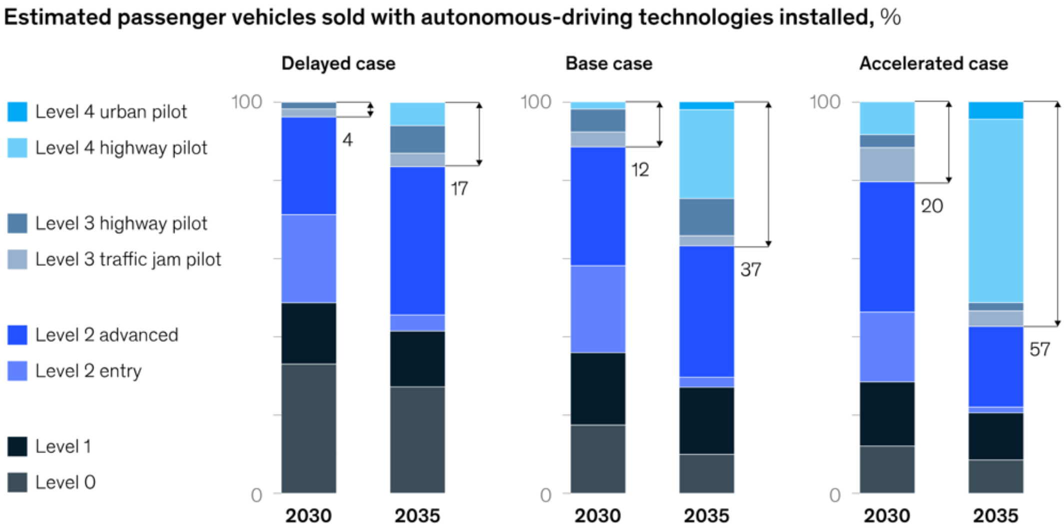


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Table 2 illustrates the projection that vehicles will ultimately achieve SAE Level 4, or driverless control under certain conditions (McKinsey, 2023). Level 4 autonomous driving has found extensive applications, particularly in the field of autonomous taxis, highlighting its broader potential as a future mainstream autonomous driving technology. The author holds high expectations for the significant potential that Level 4 autonomous driving technology can demonstrate in future transportation scenarios.

New Context

In the evolving landscape of future mobility, the role of automobiles is poised for significant transformations. Autonomous vehicles, in particular, will redefine concepts of ownership and sustainability, leading to new behavioral patterns, evolving demands, and the emergence of innovative urban mobility systems centered around vehicles.

One relevant concept in recent years is Mobility as a Service (MaaS), which embodies a novel idea that redefines our perception and engagement with mobility. It can be seen as a concept, a contemporary phenomenon accompanied by emerging behaviors and technologies, or even as a revolutionary transport solution that seamlessly integrates various modes of transportation and mobility services (Jittrapirom, P. et al., 2017).

Additionally, a new approach known as "Mobility as a Feature (MaaF)" considers mobility services as inputs into a broader activity-based paradigm of service delivery. It acknowledges that transport and travel stem from broader needs, emphasizing the importance of integrating non-transport services to effectively meet these needs (Hensher, D. A., & Hietanen, S., 2023).

The emergence of both Mobility as a Service (MaaS) and Mobility as a Feature (MaaF) is poised to profoundly impact the future landscape of mobility. The convenience of this ecosystem will further reduce the demand for private transportation, blurring the boundaries between private and public transportation, presenting a unique scenario for future mobility.

New Scenario

Dannemiller, K. A. et al. (2023) introduced intriguing concepts - travel-based activities (TBAs) and activity-based travel (ABT). This represents the first comprehensive exploration of the kinds of activities that individuals are likely to pursue when relieved from the task of driving in the era of fully automated vehicles (AVs). They refer to such activities as travel-based activities or TBAs. The results indicate that the highest impact of AVs will likely be on the number of long-distance trips, with such trips increasing.

2. Future Cockpit

Given the changes in future mobility, the role of the future cockpit becomes flexible and diverse with the advent of the driverless era. Therefore, there are four challenges to be faced when researching and designing the future cockpit: privacy, safety, activities, and driving experiences (Kun, A. L. et al., 2016). Among them, the latter three are the most widely concerned.

Driving and Safety

Under the premise of L4 autonomous driving, artificial intelligence can address most driving safety concerns for humans. However, three main security issues persist: Taking over Requests (TORs), visualization of speed, and lane change decisions (Shah, A. H., & Lin, Y., 2020). This emphasizes the necessity of traffic warning systems in the era of autonomous driving. Even though driving behaviors are no longer the primary focus, passengers still require access to pertinent traffic information in specific situations.

Driving and Activities

The study of non-driving behavior of drivers and passengers under L4 autonomous driving conditions primarily focuses on two main aspects: individual behavior and group interaction.

For individual behaviour, several surveys have highlighted some primary activities, including sleeping, listening to music, browsing mobile phones, reading, and admiring the scenery outside the window (Hecht, T. et al., 2020; Parida, S. et al., 2020; Pfleging, B. et al., 2016; Pollmann, K. et al., 2019; Russell, M., 2011).

What's more, group interactions in the context of autonomous driving primarily revolve around communication (Ive, H. P. et al., 2015). However, it's important to note that there is still a relatively limited amount of research in this area. Nevertheless, these studies lay the foundational groundwork for subsequent design endeavors.

Driving Experience

In the era of L4 autonomous driving, the driving experience, also known as the ride experience, presents two significant aspects that deserve attention: psychological experience and physical experience.

Psychologically, when users are no longer in control of the car's operations, understanding the vehicle's intentions becomes essential for them to feel safe and secure. Löcken, A. et al. (2016) point out that the transition from human drivers to automation raises complex issues. One of the key challenges, particularly in Level 3 automation, is the "Increasing complexity" of the automation systems. With the growing complexity of automation, it becomes harder for drivers to understand and monitor the car's actions.

Table 3. Frequency and severity of motion sickness for adults while watching video or reading in a moving conventional vehicle (Sivak, M., & Schoettle, B., 2015)

Measure	Activity	
	Viewing video	Reading
Frequency: *Often, usually, or always*	15%	26%
Severity: *Moderate or severe*	15%	32%

Physically, it is posited that an increasing number of non-driving activities will make motion sickness a more significant concern in self-driving vehicles compared to traditional, human-driven vehicles (Sivak, M., & Schoettle, B., 2015) (see Table 3). This expectation arises from the fact that the three primary factors contributing to motion sickness, namely conflicts between vestibular and visual inputs, the inability to predict the direction of motion, and the absence of control over the direction of motion, are heightened in self-driving vehicles. However, it's worth noting that the frequency and severity of motion sickness are influenced by the specific activities that individuals engage in while in the vehicle, rather than the act of driving itself.

Design Opportunity

In the context of driving automation, considerable attention has been given to the sense of safety, and various solutions have emerged. However, in the context of Level 4 autonomous driving, non-driving activities are poised to significantly expand and diversify within the cockpit, potentially leading to increased occurrences of motion sickness among passengers. Therefore, the author contends that motion sickness arising from non-driving activities in the era of autonomous driving presents a promising design opportunity.

1. Motion Sickness

Causes

Spencer Salter et al. (2019) underscore the increasing prevalence of rearward-facing seats in automated vehicles (AVs). However, adopting a rearward orientation in AVs may compromise the passenger experience, particularly with regard to motion sickness. Meanwhile, Michael J. Griffin and Kim L. Mills (2002) noted that the direction of motion (fore-and-aft or lateral) did not significantly impact the occurrence of motion sickness.

Michael J. Griffin and Maria M. Newman (2004) further emphasize the importance of the visual scene in motion sickness within cars. They recommend mitigating motion sickness by providing visual information while deepening understanding of the various factors influencing its occurrence or relief.

In addition, research by Ouren X. Kuiper et al. (2020) indicates that unpredictable motion induces motion sickness more significantly compared to predictable motion. These findings suggest that motion sickness arises from the disparity between sensed and expected motion, rather than simply being unprepared for the motion.

Existing Solutions

Addressing motion sickness stemming from the aforementioned causes,

Figure 2. Illustration of prototypical LED feedback system (Bohrmann, D. et al., 2022)

several potential solutions have emerged. For instance, Dominique Bohrmann et al. (2020) explored the efficacy of active seat belt retractions as a countermeasure against motion sickness. Millard F. Reschke et al. (2006) attempted to alleviate motion sickness-related gastrointestinal symptoms and motor disorders while inhibiting vestibular-autonomic pathways by using stroboscopic light synchronized to the motion pattern.

It is noteworthy that Bohrmann, D. et al. (2022) demonstrated, through a prototypical LED feedback system visualizing longitudinal driving dynamics in the passenger's peripheral visual field (see Figure 2), that integrating peripheral visual information in automated vehicle experiences could potentially enhance users' situation awareness and reduce the occurrence of motion sickness.

In summary, the prevalence of motion sickness is expected to rise significantly with the widespread adoption of autonomous driving, attributed to unique seating orientations and unpredictable motions. While various methods exist to alleviate motion sickness, providing users with visual stimuli that align with their expectations and anticipated motion appears the most promising and practical approach. Light, therefore, emerges as a favorable medium to intervene in this process.

2. User Research

To gain a deeper understanding of the characteristics of individuals suffering from motion sickness and to identify the final target demographic for the design, the author developed the following questionnaire and distributed it to a broad spectrum of respondents (see Table 4).

Research on Motion Sickness Phenomenon

*1. Your gender [single choice question] **
○Male
○Female

2. Your age
*[Enter a number from 15 to 60]**
____

*3. Do you often get motion sickness? [Single choice question] **
○Yes
○No (please skip to the end of the questionnaire and submit your answer sheet)

4. In which scenario are you more likely to get motion sickness?
*[Single choice question] **
○Long-distance travel
○Short commute
*○Others ___________ **

*5. Your travel companions are usually [single-choice question] **
○Family
○Companion
○Friends
○Traveling alone
*○Others ___________ **

Depends on option 1 of question 4

*6. What type of vehicle do you usually ride in [Single choice question] **
○Car
○SUV/MPV
*○Others ___________ **

*7. What do you usually do on a car ride? [Multiple choice questions] **
☐Listen to music
☐Playing with mobile phone
☐Chat with peers
☐Diet
☐Call
☐Look at the scenery
*☐Others___________ **

*8. What may cause you to get motion sickness [Multiple choice questions] **
☐Closed space/poor ventilation
☐Poor shock absorption/poor road conditions
☐Many turns/many stops
☐Seat comfort
☐Seating position
*☐Others___________ **

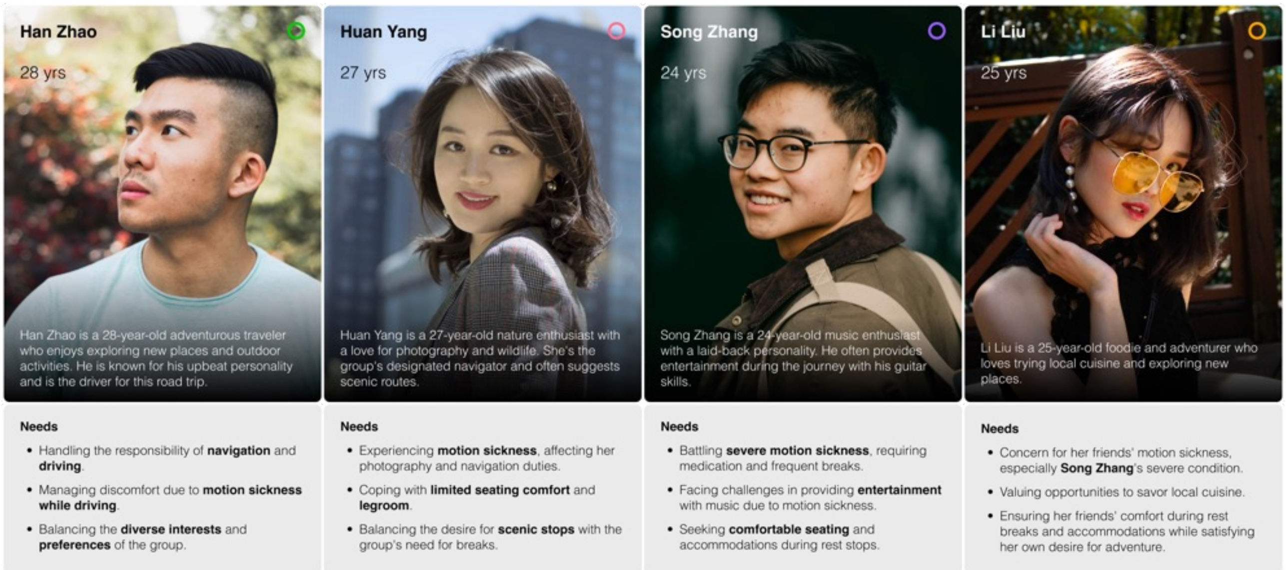
Table 4. Research on motion sickness phenomenon

A total of 117 questionnaires were collected for this survey, with 71 of them deemed valid. The research results indicate that the majority of surveyed individuals experience motion sickness during long-distance trips (59.15%) with family (42.86%) or friends (30.95%), primarily due to unpredictable traffic conditions (71.83%). This offers the author a clear design focus and scenario, which will be reflected in the construction of user profiles and user journeys in the next phase.

3. Design Approach

Based on the research findings, the author has chosen the scenario of long-distance travel with friends to create personas (see Table 5) and user journeys for the target users.

Table 5. Persona in long-distance travel with friends (Photo retrieved on Unsplash)



In the scenario of friends traveling together, it is crucial to consider both the need for privacy for individual passenger behaviors and the flexibility required for group interactions. However, paramount considerations remain the demand for comfortable seat configurations and the mitigation of potential motion sickness risks (see Table 6).

Table 6. User journey of long-distance travel with friends

	Planning	Departing	Travelling	Arriving
User Journey	Discussing; Planning; Planning	Set Route; Packing	Chatting Together; Gaming; Resting; Reading; Videos	Worrying
Touch Point	Friends Gathering; Internet / APP / Map	APP / Car Interface; Suitcase / Car Interior	Car Interior; Devices / Car Interior	Car Interior
Needs	Comfortable And Safe Way To Travel	Comfortable Environment In The Car	Comfortable And Stable Activity Environment	Relieve Motion Sickness
Pain Point	Looking Forward To More Interactive Time	Comfortable Seats And Interior Design	Reduces Motion Sickness During Activity	Motion Sickness Solution

The analysis suggests that the seat is the closest and most effective touch point with passengers. By offering flexible and comfortable seating options, combined with a well-designed lighting system, there is an opportunity to enhance the overall riding experience, including alleviating motion sickness.

Figure 3. Cockpit layouts research (Photo retrieved on Pinterest)

Project

1. Space Design

In preparation for designing the seats, thorough research and analysis are essential to accommodate potential non-driving activities for both individuals and groups within Level 4 autonomous driving cockpits. Various cockpit layouts from existing and conceptual designs have been examined by the author (see Figure 3).

Figure 4. Graphical illustration of researched cockpit layouts

After compiling and organizing numerous relevant conceptual designs, the author meticulously categorizes and analyses them based on seat number, form, and layout (see Figure 4) with the aim of identifying designs that meet specified requirements.

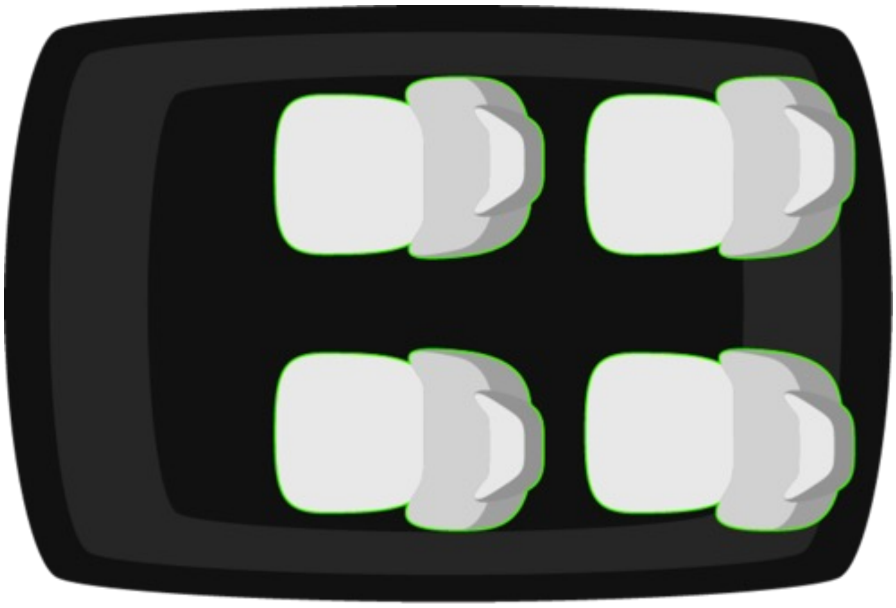


Figure 5. Final design decision of cockpit layout

Considering the configuration requirements of L4 autonomous driving (such as the retention of driver's seats), the selected design concept offers a balanced approach, enhancing traditional cockpit layouts by replacing fixed seating with four rotating seats (see Figure 5). This modification maintains basic functionality while enabling seats to rotate 90 degrees sideways, facilitating group interactions and significantly reducing motion sickness risks. Such design ensures cockpit passengers' flexibility and potential for interaction.

Moreover, the uniform and interchangeable design of all four independent seats expands market possibilities, reduces maintenance and storage costs, and lowers potential manufacturing expenses.

2. Product Design

Figure 6. The Egg Chair (Arne Jacobsen, 1959)

Inspiration

Among various case studies, "The Egg chair" by Arne Jacobsen (1959) stands out as a significant source of inspiration (see Figure 6). This Danish design masterpiece, crafted through experimentation with wire and plaster in Jacobsen's garage, profoundly influences the author's design process. The enveloping shape of The Egg Chair not only ensures ample privacy and comfort but also provides an ideal location for integrating the lighting system in later stages.

single car seat,	Product Definition
industrial design,	Domain Definition
white color,	CMF Constraint
Arne Jacobsen,	Style Constraint
pure white background,	Image Background
studio lighting,	Lighting Configuration
right angle shot	Camera Setting
--s 50	Stylizing Strength
--c 0	Chaos Strength
--ar 1:1	Image Specification
--v 5.2	Core Version

Table 7. Prompt for references generation with Midjourney

AI-facilitated Design

This project endeavors to explore how Artificial Intelligence Generated Content (AIGC) can optimize workflows for industrial designers. The chosen AI tool, the well-established Midjourney image generation platform, aids in generating a series of visual references.

The author utilizes the prompt "single car seat, industrial design, white color, Arne Jacobsen, pure white background, studio lighting, right angle shot" (see Table 7). Despite minimal design-related terms beyond image quality constraints, the inclusion of the somewhat biased term "Arne Jacobsen" ensures consistent and controllable style in the generated results, particularly concerning the later integration of the lighting system.

Figure 7. Generated references (Photo generated by Midjourney)

Ultimately, the author successfully generates numerous design references using Midjourney (see Figure 7). However, the existing cues proved insufficient for selecting and finalizing the design concept. The absence of consideration for the lighting system's positioning in the generation process suggests utilizing this constraint to refine and approach the final design concept.

Design Refinement

Given the necessity for the lighting system to coexist with passengers' non-driving activities and convey specific informational content, the precise placement is paramount.

Referencing Spector, R. H. (1990), who introduced the concept of peripheral vision, it's noted that signals appearing within passengers' peripheral vision are still noticeable. Additionally, research by Strasburger, H. et al. (2011) highlights humans' ability to reconstruct and interpret compressed and distorted information perceived peripherally, facilitating appropriate information delivery during focused non-driving activities.

Consequently, three potential locations for the light—near the head, shoulder, and body—were identified to effectively convey driving information to passengers (see Figure 8).

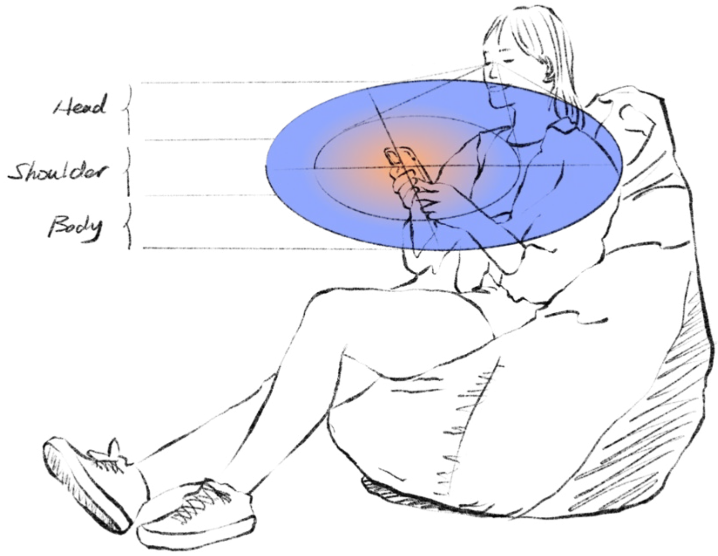


Figure 8. Potential location for lighting system

HOODIE - Seat Design for Motion Sickness

As a result, the author developed HOODIE, a car seat designed to mitigate motion sickness resulting from Level 4 autonomous driving (see Figure 9). Enveloping passengers within a large shelter enhances privacy while the anti-motion sickness light warning system, integrated into the shelter, reduces motion sickness occurrences through preemptive warnings.

Figure 9. HOODIE - Seat Design for Motion Sickness

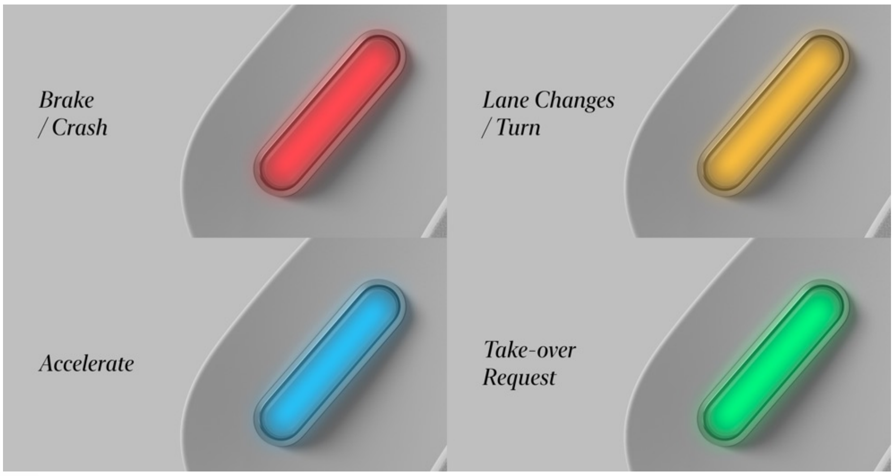


Figure 10. Examples of anti-motion sickness light warning system

The anti-motion sickness light warning system alerts users before the autonomous driving system detects motion trends. For instance, red lights indicate braking or imminent collision, while yellow lights signal lane changes or turns (see Figure 10). Furthermore, warnings are provided for accelerations or take-over requests . This design also addresses passengers' security concerns regarding driving conditions.

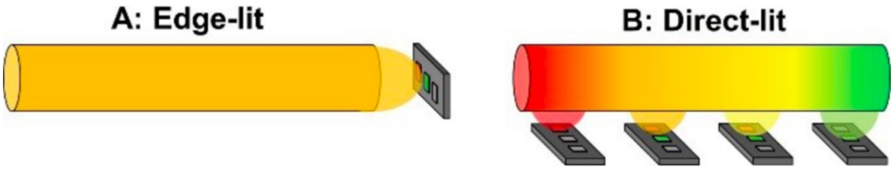


Figure 11. Left (A): Static edge-lit system. Right (B): Dynamic direct-lit system (Blankenbach, K. et al., 2019)

To ensure rapid light signal responsiveness to vehicle motion, the author selected ISELED technology (Blankenbach, K. et al., 2019) as the technical foundation. This technology addresses challenges associated with maintaining luminance and color uniformity across various temperature conditions in direct-lit light guides, which could synchronize effectively with in-car entertainment systems, offering rich lighting effects and potential for developing more complex animations (see Figure 11).

As previously discussed, HOODIE's cockpit layout features four independently rotatable seats, facilitating passengers' mobility and communication and supporting various scenarios. For instance, the four scenarios depicted in Figure 12 demonstrate passengers' ability to choose and configure seat layouts according to different situations, allowing for individual activities or face-to-face communication.

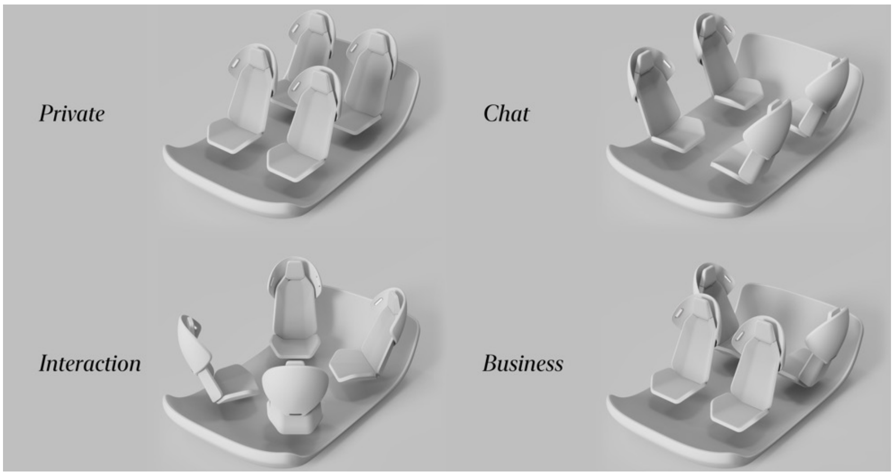


Figure 12. Flexible cockpit layouts in different scenarios

Conclusion

In summary, extensive literature exploration supports the imminent widespread adoption of Level 4 autonomous driving technology, which will significantly impact urban transportation systems. The study underscores the potential for personal transportation in long-distance travel scenarios and addresses challenges posed by increased motion sickness through innovative solutions like HOODIE.

Moreover, by analysing automotive cockpit layouts, the study proposes a visionary concept tailored for Level 4 autonomous driving. This design features four independently swivelling seats, aiming to prevent motion sickness while accommodating diverse passenger activities.

Limitation

While the proposed concept may mitigate motion sickness in future L4 autonomous driving, further exploration is needed regarding interactivity, ergonomics, market analysis, and user strategies to enhance implementation comprehensively. These areas present opportunities for future research and development, building upon this foundational exploration to create stronger and more effective solutions for motion sickness in autonomous driving scenarios.

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