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Designing for Comfort: Non-Driving Activities in Level 4 Autonomous Vehicles

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Abstract: *Autonomous vehicles are expected to provide a higher level of freedom and comfort for passengers due to their interior design. The interior packaging of autonomous vehicles is focused on non-driving related activities (NDRAs), unlike conventional vehicles, which are centered around the driving task. In levels 0-3 of automation, drivers must remain engaged in the driving task. This means that they may perform certain NDRAs while also performing driving tasks, depending on the level of automation. However, at level 4, driver intervention is not required for most of the journey, which causes the design shift from driving task centered to non-driving related activities centered, prioritizing comfort and user experience. In this paper, we discuss non-driving related activities in level 4 autonomous vehicles based on various situations of vehicle use. We propose a new framework clarifying the drivers' state and discuss the main design element that should be focused on interior design of autonomous vehicles.*

Keywords: *Interior design, autonomous vehicle, non-driving related activities, comfort*

I. INTRODUCTION

The advancement of autonomous driving technology has changed the driving scenarios of drivers and shifted the center of interior design of modern cars. According to the regulations of the Society of Automotive Engineers (SAE) [1], the levels of autonomous driving are divided into six levels. These are: Level 0 - No Automation, the driver needs to fully control the vehicle; Level 1 - Driver Assistance, only the steering and acceleration/deceleration tasks can be assisted by the vehicle system; Level 2 - Partial Automation, only the steering and acceleration/deceleration tasks can be completed by the vehicle system, but the driver needs to monitor the entire process; Level 3 - Conditional Automation: the vehicle can complete all driving tasks but still requires the driver to monitor the entire process and be prepared to take control at any time; Level 4 - High Automation: the vehicle can complete all driving tasks and does not require driver monitoring, except in a few special situations, such as traffic jams; Level 5 - Full Automation: the vehicle

autonomously completes all driving tasks, without the need for human attention or intervention.

As we move from Level 0 to Level 5, the human driver's intervention progressively decreases while the vehicle's autonomous capabilities increase. In traditional vehicles, the interior design is centered around the driver, with controls and instruments placed within easy reach. However, as autonomous driving technology advances, the need for these traditional controls is reduced or even eliminated. This shift allows for a reimagining of vehicle interiors, transforming them into spaces for work, relaxation, or entertainment. The focus of interior design thus shifts from driving task centered to non-driving related activities centered, prioritizing comfort and user experience.

Non-driving-related activities or tasks (NDRAs) refer to tasks or activities that are not related to driving the car. In [2], Bastian et al. investigated the users' expectations and demands for NDRAs during highly automated driving. These activities can be performed by the driver or passengers while the car is in motion and do not require any attention to the road or control of the vehicle. Examples of NDRAs include talking to passengers, listening to music, daydreaming, writing text messages, eating, and drinking, browsing the Internet, and making phone calls. With the advent of highly automated driving, drivers will be able to engage in NDRAs while the car is in motion without having to steer or monitor their car.

In this article, we will analyze the driver's behaviors in an autonomous vehicle and present a conceptual framework which categorizes the state of occupants and influencing factors. Some preliminary concepts of interior design of autonomous vehicles will be presented at the end.

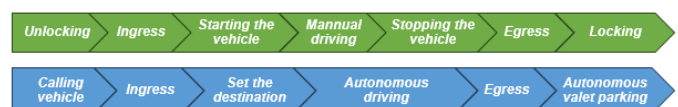


Figure 2.1 Comparison of vehicle operating procedure between traditional vehicles (green chart) and autonomous vehicles (blue chart).

II. CONCEPTUAL FRAMEWORK ABOUT HUMAN FACTORS AND INTERIOR DESIGN ON LEVEL 4 AUTONOMOUS VEHICLE

In the near future, the most commercially used autonomous vehicle is likely to be level 4. This is due to the difficulties to determine liability for accidents in level 3 autonomous vehicles, which still require driver intervention at any time. In contrast, the procedure to operate a level 4 autonomous vehicles is much simpler compared to that of traditional vehicles, as show in figure 2.1, and no requirement of human intervention in most driving scenarios make it clear to tell the responsibilities.

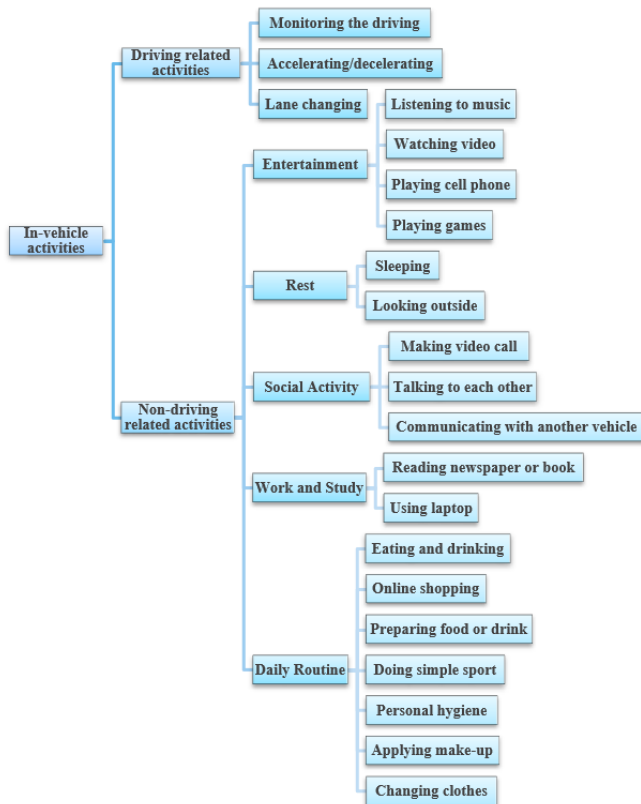


Figure 2.2 The activities that a driver may perform in autonomous vehicles.

A. Non-driving-related activities (NDRAs)

The tasks and activities that a driver needs or wants to perform in operating a vehicle are typically divided into driving-related activities (DRAs) or tasks and non-driving-related activities (NDRAs)[3], as shown in figure 2.2. DRAs include all activities required to maneuver the vehicle, such as lateral and

longitudinal control and maintaining awareness of traffic and potential hazards. NDRAs encompass all other tasks, including operating the windscreen wipers or turn indicators, adjusting comfort features such as heating, using infotainment systems, communicating with passengers or the outside world, and eating or drinking.

When these driving tasks are applied to an autonomous vehicle, the need for the driver to monitor the traffic situation decreases, leaving only simple tasks such as defining the destination upon entering the vehicle. This allows the driver to engage in a greater number of new NDRAs. In fully automated driving scenarios, NDRAs will make up most of the vehicle's activities. These activities will no longer pose a danger as they do in manual driving but will instead become a normal and reasonable occurrence. However, NDRAs can still affect road safety by impacting the driver's takeover performance.

B. Drivers' state in level 4 autonomous vehicles.

Autonomous vehicles are anticipated to provide an enhanced comfort experience [4]. However, comfort is a subjective concept that is difficult to quantify and lacks a standard and universal scientific definition [5]. While some individuals view comfort and discomfort as opposite ends of a spectrum, others perceive them as distinct concepts. Our study does not focus on defining comfort or developing a methodology for testing it, but rather on clarifying the driver's state and identifying the activities they are engaged in specific scenarios, as shown in figure 2.3.

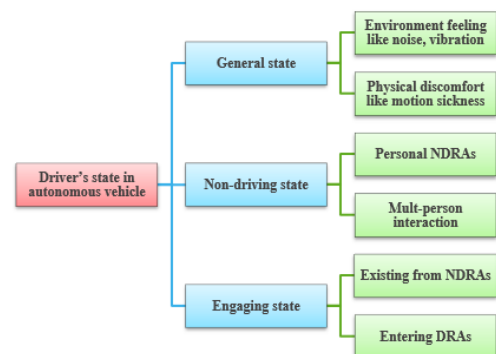


Figure 2.3 The Drivers' state in autonomous vehicle and corresponding factors

The general state refers to the driver's overall wellbeing throughout the journey. From the moment the passenger boards

the vehicle until they leave, they remain in a comfortable state regardless of their activities. There is comfort related to environmental factors such as vibration [6], noise [7]. There is also discomfort like motion sickness caused by the lack of driving. The comfort and discomfort experienced by drivers can influence their choices about autonomous driving style. For example, [8] studied driver preferences for acceleration and lane change strategies.

The non-driving state refers to the activities that the driver and passengers can freely engage in while the vehicle is autonomously driving. During this time, the driver may choose to relax, work, or engage in entertainment. Some research has focused on individual activities such as sleeping [9], while other studies have examined multi-person activities scenario and tested new interior seat configurations [10].

The engaging state refers to the occasional and brief instances where the driver is prompted by the system to monitor or operate the vehicle. During this process, the driver must exit from the NDRA and enter DRAs. Although infrequent, this process must be considered in the design of autonomous vehicles [11].

C. The three elements of interior design in autonomous vehicles

The design of traditional vehicles is centered around better serving the driver's driving tasks. Interior elements such as instrument panels, steering wheels, and center consoles need to be accessible to the driver while driving and must not affect driving safety. In level 4 autonomous vehicles, however, the driver is no longer responsible for driving and the focus of interior design shifts to better serve people's NDRA. Therefore, we think that the three powerful interior design elements in autonomous vehicles are screens, seats, and tables.

The first element, screen, is not only the medium through which drivers control autonomous vehicles, but also the primary method of entertainment. It is where most human-vehicle interaction occurs, and drivers can obtain vehicle state information such as speed, mileage, current location, vehicle maintenance information, predicted traffic information, and state of cruise control.

Many car manufacturers, including Tesla and Mercedes-Benz, have introduced cars with large touch screens and multiple LCD screens. The integration of multiple screens including the LCD instruments, HUD, the control screen, and the car information

terminal, HMI entertainment screen, is becoming increasingly common [13].



Figure 2.4 2024 Mercedes-Benz E-Class showcases the sedan's massive Super screen dashboard displays.[12]

The seats are a crucial element in determining the main layout of the interior space. It is important to design a flexible layout that can accommodate different aspects of the overall space, such as cinema layout, face-to-face chatting layout, sleeping layout, etc. Besides, the seats will need to be designed to provide maximum comfort and flexibility, with the ability to recline, swivel, and adjust to different positions.



Figure 2.5 XiM17 (eXperience in Motion 17) Demonstrator Vehicle [14]

For instance, Yangfeng Automotive proposed the interior XiM17 autonomous vehicle concept, as shown in figure 2.5. In their design, seats can rotate and slid to adapt to different usage scenarios including driving mode, family mode, meeting mode, and lounge mode.

The third element of the interior design in autonomous vehicles is the table. Although there is currently relatively little research on it, the table still plays an important role in serving NDRA's on autonomous vehicles. Under normal circumstances, a small table is needed to place water, mobile phones, and other

frequently used objects. In an office working scenario, a table is needed to place books, computers, and other work-related items, as shown in figure 2.6. The key point will be the ergonomic dimensions, as well as the position of placement of these tables.



Figure 2.6 Engineering interior design for passenger comfort [15]

III. CONCLUSION AND PERSPECTIVES

This paper presents a review of the literature on the study of interior design of autonomous vehicles centered on non-driving related activities and proposes a new conceptual framework for the classification of drivers' state based on corresponding users' cases, and discussed about the three main element (screen, seats and tables) of interior design of future autonomous vehicle.

Safety design, not discussed in this paper, is still indeed an essential part of the interior design of autonomous vehicles. The design of vehicle restraint systems needs to change to accommodate the freedom to perform non-driving related activities. Additionally, how to ensure that the driver can clearly accept the takeover signal sent by the car system and quickly and smoothly control the car in specific situations, will be new safety issues brought about by autonomous driving.

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