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Examining the Role of Driver Perception in Takeover Time: Application of Task-Capability Interface Theory

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Abstract— **Conditionally automated driving enables drivers to engage in non-driving-related activities, with the responsibility to take over vehicle control upon request. This takeover process increases the risk of collisions, especially when drivers fail to safely complete takeovers within limited time budgets (i.e., the time offered by automation for takeovers). This phenomenon underlines the significance of providing time budgets that sufficiently accommodate drivers' takeover time (i.e., the time required by drivers to resume conscious control of vehicles). Considering that drivers' takeover time varies significantly across scenarios, this study centres on understanding the role of driver perception in takeover time using the Task-Capability Interface (TCI) theory. The TCI theory suggests that drivers adjust their behaviours based on their perceived task demands and driver capabilities. Accordingly, in a driving simulator experiment featuring diverse traffic densities and distractions, we investigated drivers' takeover time while capturing their perceived task demands and capabilities through a takeover-oriented questionnaire based on established instruments. The results show that drivers generally have longer takeover time as their perceived task demand rises, perceived driver capability diminishes, and perceived spare capacity (perceived driver capability minus perceived task demand) decreases. These patterns fluctuate under conditions of low perceived task demand or high perceived driver capability. When both conditions coincide, drivers necessitate a considerably longer time to regain vehicle control. Our findings on takeover time contribute to the development of strategies aimed at predicting drivers' takeover time, optimizing time budgets, fostering human-centred vehicle design, and enhancing the safety of conditionally automated driving.**

I. INTRODUCTION

Conditionally automated driving implies a paradigm shift: Drivers can engage in non-driving-related activities, while they have to serve as a safety fallback and take over vehicle control upon request. Ensuring that drivers are capable of resuming manual control safely is of utmost importance. Research has demonstrated that takeover requests can impose substantial cognitive demands on drivers [1]–[3], particularly in human-out-of-the-loop scenarios [4], [5]. This can increase the risk of collisions if drivers do not manage to safely resume manual control of vehicles within limited time budgets. Given the intricacies of human-vehicle interactions involved in control transitions, providing sufficient time budgets that enable safe takeovers persists as an open challenge.

A commonly acknowledged time budget in the literature for distracted users to regain control of a vehicle is 7 seconds [6]–[8]. In on-road situations, Mercedes Benz offers drivers 10 seconds to resume vehicle control [1]. The adequacy of these time budgets for ensuring safe takeovers, particularly in complex scenarios, requires further investigation. We argue that the adequacy of a time budget hinges on its relationship with drivers' takeover time (i.e., the time from the initiation of takeover requests to the resumption of conscious manual control of vehicles [9]). On one hand, time budgets that are inadequate to cover drivers' takeover time can endanger the safety of takeovers, as drivers do not have enough time to respond properly [10], [11]. On the other hand, time budgets that are excessively longer than takeover time can also pose potential risks, as such takeover requests can be perceived as false alarms and receive limited attention [12], [13]. This circumstance underscores the importance of understanding drivers' takeover time, which is the focus of this paper.

Understanding drivers' takeover time requires identifying determinants of takeover time, including non-driving related task [14], workload [1], situation awareness [15], [16], etc. These determinants are intricately interconnected, posing challenges to modelling and predicting drivers' takeover time. In this case, neural networks have been adopted for their ability to capture complex relationships and patterns within data. For example, [17] introduced Deep Take, a deep neural network-based framework, to predict drivers' takeover time using vehicle data, driver biometrics, and subjective measurements. [18] employed an eXtreme Gradient Boosting model rooted in decision trees to predict drivers' takeover time, considering multiple factors such as time budgets, non-driving related tasks, takeover request modalities, and scenario urgency. These neural network models possess two primary limitations: (i) these models generally lack a solid theoretical foundation for the selection of input variables, which may compromise the robustness of their results by not accounting for lurking factors [19], and (ii) the opacity of these models diminishes both algorithm interpretability and result reliability. These limitations can introduce uncertainties and potential safety risks to takeovers.

To mitigate the above limitations, this study investigates drivers' takeover time from the perspective of the Task-Capability Interface (TCI) theory. The TCI theory suggests that drivers adjust their driving behaviours based on the dynamic interactions between their perceived task demand (pTD) and perceived driver capability (pDC) [20]. We utilize this TCI theory to interpret drivers' takeover time for two reasons:(i) pTD and pDC are derived from drivers'

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[1]https://group.mercedes-benz.com/company/magazine/technology-innovation/easy-tech-drive-pilot.html

comprehensive perception of diverse factors in the driving environment [21], which can be used to enhance the robustness of models of takeover time, and (ii) TCI theory has been validated across various driving contexts [22]–[24], which holds the potential to provide a solid theoretical foundation for modelling and predicting takeover time. Therefore, we argue that TCI theory can help to improve the interpretability of models of takeover time, optimize the determination of sufficient time budgets, and enhance the safety of takeovers.

From the perspective of TCI theory, we explore drivers' takeover time by examining drivers' pTD and pDC for takeovers. Specifically, drivers' pTD [21] for takeovers represents their subjective assessment of the complexity involved in resuming conscious control of the ego vehicle from conditionally automated driving systems within a specific scenario. Drivers' pDC [21] for takeovers denotes their subjective assessment of their momentary ability to regain conscious control of the vehicle from conditionally automated driving systems at a specific moment. We argue that drivers' pTD and pDC for takeovers hold the potential to represent drivers' holistic perception of the entire takeover situation. Such perceptions play a decisive role in drivers' takeover time, as situational awareness models underscore the perception of the environment as the fundamental procedure in human decision-making processes [25].

To further explore drivers' takeover time through the lens of TCI theory, this study constructs three hypotheses:

1 Drivers' takeover time increases with higher pTD.
2 Drivers' takeover time increases with lower pDC.
3 Drivers' takeover time increases with lower perceived spare capacity (i.e., pDC minus pTD).

To empirically test these hypotheses, this study implements a driving simulator experiment, exposing drivers to nine takeover scenarios. The experimental design incorporates variations in drivers' pTD and pDC for takeovers through a structured combination of 3 traffic densities and 3 n-back tasks (see Section II-B). Drivers' takeover time is measured by their first conscious lane-changing, braking, or accelerating inputs (whichever occurs first) following takeover requests. Meanwhile, drivers' pTD and pDC are measured via a questionnaire modified for takeover contexts from well-established instruments. On these bases, we investigate the relationships among experimental treatments (traffic densities and n-back tasks), TCI-informed constructs (drivers' pTD and pDC), and drivers' takeover time. Results reveal that drivers' takeover time exhibits: (i) positive correlation with their pTD, (ii) negative correlation with their pDC, and (iii) negative correlation with their perceived spare capacity (i.e., pDC minus pTD). Variations are evident in these patterns when drivers face low perceived task demand or high perceived driver capability. In instances where both conditions align, drivers require notably more time to resume vehicle control. The understanding of these relationships can aid in developing predictive models for drivers' takeover time and contribute to determining sufficient time budgets for safe takeovers. This study aims to provide insights to readers who are in search of theoretical foundations for models of takeover behaviours, as well as those who are interested in optimising human-vehicle interactions in automated driving.

II. METHOD

The driving simulator experiment and questionnaire in this study were approved by the Human Research Ethics Committee (HREC) of Delft University of Technology (ID: 3499). Participants were recruited (Section II-A) and were required to (i) complete nine takeover tasks (Section II-B), and (ii) fill in a takeover experience questionnaire regarding their pTD and pDC for each takeover (Section II-C). Data resulting from the experiment and the questionnaire were subject to analysis using the methods in Section II-D.

A. Recruitment

An advertising poster was distributed both online (via emails and LinkedIn) and offline (via flyers). Recruitment criteria are access to (i) having a valid driver's license, and (ii) having a normal or corrected-to-normal vision without wearing glasses. Potential participants were briefed on the details of this study and were asked to express their willingness to participate by signing the Informed Consent Forms.

B. Driving simulator experiment

The experiment took place in a fixed-base, medium-fidelity driving simulator, featuring a two-lane motorway environment. The automated driving speed is 100 km/h, the upper speed limit on motorways during daytime in the Netherlands. The system boundary is two colliding vehicles occurring ahead of the ego vehicle. A takeover request is initiated when the time headway between the collision and the ego vehicle reaches 7 seconds which is a widely-recognized time budget [7], [8], [11]. The request provides three beeps and shows three lines of text message "Please Take Over!" on the top left corner of the windshield (see Figure 1).

Fig. 1: A view from the driver's seat in the driving simulator.

The experiment adopts a 3 (traffic densities) $\times$ 3 (n-back tasks) repeated measure design to vary drivers' pTD and pDC for takeovers. Traffic densities are set as $0/10/20$ vehicles per kilometre. N-back tasks ($n = 0, 1, 2$) are implemented to induce varying distraction levels among participants. Specifically, participants are presented with a sequence of positions of a blue box and are instructed to press a button when the new position matches the one that occurs n steps back in the sequence. These nine takeover scenarios are arranged by Latin Square design [26] to appear in a balanced order, with participants being assigned to each scenario equally based on gender and age group. Participants are required to immediately disengage from the n-back task and start to resume vehicle control after they receive the takeover request. After each takeover, participants take a break and report their pTD and pDC via the questionnaire in Section II-C. Each participant received a 20-euro voucher.

C. Takeover experience questionnaire

The takeover experience in this study refers to two constructs: pTD for takeovers (Section II-C.1) and pTDC for takeovers (Section II-C.2). The questions measuring these constructs were presented in random order to reduce order effects. Participants were asked to indicate their agreement with the scale statements on a five-point scale (1 = Strongly Disagree, 5 = Strongly Agree).

1) Perceived task demand for takeovers: Drivers' pTD for takeovers is deconstructed into their perceived mental demand ($\mathrm{pTD}_{\mathrm{mental}}$), visual demand ($\mathrm{pTD}_{\mathrm{visual}}$), and temporal demand ($\mathrm{pTD}_{\mathrm{temporal}}$) for takeover contexts. Accordingly, three scales for measuring drivers' pTD are developed based on NASA Task Load Index (NASA-TLX) [27] and Driving Activity Load Index (DALI) [28], as listed in Table I.

2) Perceived driver capability for takeovers: This study extends the scales in [29] and deconstructs drivers' pDC for takeovers into five distinct dimensions based on the Driver Skill Inventory (DSI) [30], [31]. As shown in Table II, drivers' pDC is measured from their perceived anticipation capability ($\mathrm{pDC}_{\mathrm{anticipation}}$), reaction capability ($\mathrm{pDC}_{\mathrm{reaction}}$), speed adjustment capability ($\mathrm{pDC}_{\mathrm{speed\_adjust}}$), lane change capability ($\mathrm{pDC}_{\mathrm{lane\_change}}$), and safety capability ($\mathrm{pDC}_{\mathrm{safety}}$). This is because the takeover manoeuvres in this study encompass anticipating the takeover situation, resuming motor readiness in response to takeover requests, adjusting driving speed to suit the takeover situation, changing lanes to bypass the detected collision ahead, and keeping sufficient distances from surrounding vehicles [32]. The developed scales are employed to measure drivers' pDC when they have made decisions for takeover manoeuvres, i.e., when they start to take over vehicle control.

D. Data acquisition and analysis

The acquired data can be categorized into two groups:

- Data from the driving simulator: the changes in the steering wheel angle, accelerator, and braking pedal are recorded to quantify drivers' takeover time. [9] defines drivers' takeover time as the duration between the initiation of takeover requests and the start of conscious manual driving. A widely accepted indicator for the start of conscious manual driving is when the steering wheel angle exceeds 2 degrees or the braking pedal position surpasses 10% [11], [33]. Additionally, this paper considers cases where the accelerator pedal exceeds 10% as an additional indicator. This is because drivers might choose not to decelerate but instead opt to accelerate, for instance, to overtake a vehicle on the left and change lanes after receiving a takeover request.
- Data from the takeover experience questionnaire: drivers' pTD and pDC are measured via the takeover experience questionnaire that is tailored for takeover contexts. On this basis, this study adopts Raw TLX (a simplified version of NASA-TLX) [34] and computes drivers' pTD as the average of $\mathrm{pTD}_{\mathrm{mental}}$, $\mathrm{pTD}_{\mathrm{visual}}$, and $\mathrm{pTD}_{\mathrm{temporal}}$. Similarly, drivers' pDC is computed as the average of $\mathrm{pDC}_{\mathrm{anticipation}}$, $\mathrm{pDC}_{\mathrm{reaction}}$, $\mathrm{pDC}_{\mathrm{speed\_adjust}}$, $\mathrm{pDC}_{\mathrm{lane\_change}}$, and $\mathrm{pDC}_{\mathrm{safety}}$.

Drivers' takeover time, pTD, and pDC are further processed using descriptive statistics (mean values and standard deviations). The correlations between two experiment treatments (traffic densities and n-back tasks) and drivers' takeover experiences (pTD and pDC) are examined, providing insights into the internal validity of this study. Besides, the relationship between drivers' takeover time and their pTD and pDC are explored to validate the proposed hypotheses. Results are presented and discussed in Section III.

III. RESULTS AND DISCUSSIONS

A. Participants

A total of 57 drivers, comprising 33 males and 24 females, participated in this study. The age of the participants ranges from 18 to 81 years, with a mean of 38.51 (SD = 17.23). Each participant completed nine takeovers, resulting in a dataset of 513 takeovers. No simulator sickness was reported during experiments. However, 15 takeovers were deemed invalid as participants took over vehicle control before receiving the takeover request. One takeover was identified as an outlier as the participant forgot to press the button to enable manual inputs. Consequently, the study was conducted based on a refined dataset comprising 497 takeovers.

B. Relationship between experiment treatments and drivers' takeover experiences

In this section, we respectively analyze drivers' takeover experiences (pTD and pDC) across nine experiment treatments (three traffic densities $\times$ three n-back tasks). This helps to understand the effects of external treatments on drivers' cognitive activities during takeovers.

1) Treatments v.s. pTD: This study calculates drivers' pTD as the average of three sub-components: $\mathrm{pTD}_{\mathrm{mental}}$, $\mathrm{pTD}_{\mathrm{visual}}$, and $\mathrm{pTD}_{\mathrm{temporal}}$. Figure 2 presents drivers' pTD for each combination of traffic density and n-back task.

The results indicate that both traffic density and n-back task are positively related to drivers' pTD ($F(2, 494) = 41.24, p < 0.01$). As traffic density increases, drivers' pTD shows an upward trend across n-back tasks. Meanwhile, the increasing difficulty of the n-back task is associated with higher pTD across traffic densities. The influence of traffic densities on drivers' pTD is comparable to the impact of traffic densities. This circumstance suggests a potential interplay between traffic density and n-back tasks in shaping drivers'

TABLE I: Scales measuring perceived task demand for takeovers.

Latent Variable	No.	Observed Variable	Reference
Mental demand	$\mathrm{pTD}_{\mathrm{mental}}$	Taking over car control in this situation was mentally demanding.	[27], [28]
Visual demand	$\mathrm{pTD}_{\mathrm{visual}}$	Taking over car control in this situation was visually demanding.	
Temporal demand	$\mathrm{pTD}_{\mathrm{temporal}}$	The time left for me to take over car control was short.	

TABLE II: Scales measuring perceived driver capability for takeovers.

Latent Variable	No.	Observed Variable		Reference
Anticipation capability	$\mathrm{pDC}_{\mathrm{anticipation}}$	When I started to take over car control, I believed ...	I anticipated what would happen next in this situation.	[29], [30], [32]
Reaction capability	$\mathrm{pDC}_{\mathrm{reaction}}$		I responded to the takeover request promptly.	
Speed adjustment capability	$\mathrm{pDC}_{\mathrm{speed\_adjust}}$		I could adjust speed effectively in this situation.	
Lane change capability	$\mathrm{pDC}_{\mathrm{lane\_change}}$		I could change lanes fluently in this situation.	
Safety capability	$\mathrm{pDC}_{\mathrm{safety}}$		I could maintain sufficient distance from the cars around me in this situation.	

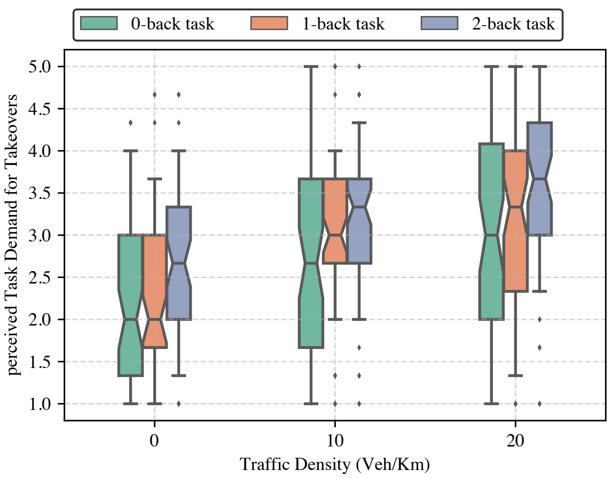

Fig. 2: Drivers' perceived task demands for takeovers across traffic densities and n-back tasks.

pTD. One explanation can be that drivers consider n-back tasks as integral components of the takeover task, leading to increased pTD as n rises. Overall, Figure 2 illustrates that the adopted experimental treatments, encompassing traffic densities and n-back tasks, can manipulate drivers' pTD. The findings partially attest to the effectiveness of the modified scales employed for assessing drivers' pTD.

2) Treatments v.s. pDC: This study calculates drivers' pDC as the average of five sub-components: $\mathrm{pDC}_{\mathrm{anticipation}}$, $\mathrm{pDC}_{\mathrm{reaction}}$, $\mathrm{pDC}_{\mathrm{speed\_adjust}}$, $\mathrm{pDC}_{\mathrm{lane\_change}}$, and $\mathrm{pDC}_{\mathrm{safety}}$. As shown in Figure 3, there is a general negative correlation between both traffic density and n-back task difficulty with drivers' pDC ($F(2, 494) = 53.34, p < 0.01$). On one hand, increasing traffic density results in a consistent decrease in pDC across n-back tasks. On the other hand, higher n-back task difficulty is generally associated with lower pDC across traffic densities. The changes in drivers' pDC remain relatively modest across n-back tasks at low and medium traffic density levels, while such changes become more significant at the high traffic density level. We conjecture this disparity is because drivers generally have sufficient capability to fulfil the takeover task while managing distractions at low and medium traffic density levels. However, at the high traffic density level, the margins between drivers' perceived capabilities and task demands become narrow. The demands imposed by n-back tasks become substantial in comparison to the available margins. Thus, drivers' pDC at the high density level are more sensitive to changes in n-back tasks. Such findings imply that the experimental treatments, involving traffic densities and n-back tasks, can manipulate drivers' pDC. The findings provide validation for the effectiveness of the modified scales used to evaluate drivers' pDC.

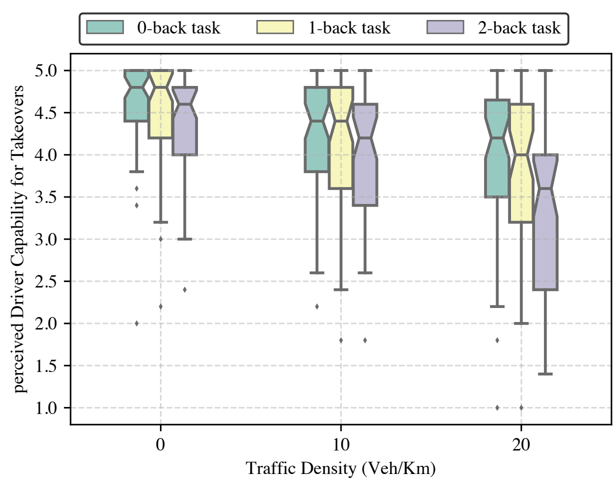

Fig. 3: Drivers' perceived takeover capabilities across traffic densities and n-back tasks.

C. Relationship between drivers' takeover time and takeover experiences

To unfold drivers' takeover time using TCI theory and test the hypotheses in Section I, this study explores the relationships between drivers' takeover time and takeover experiences (i.e., pTD and pDC for takeovers). Drivers' takeover time is measured by the interval between the takeover request and the start of conscious manual driving (when the steering wheel angle exceeds 2 degrees or the brakingaccelerator pedal position surpasses 10%). Considering the takeover experience questionnaire in Section II-C adopts five-point scales, this study divides drivers' pTD and pDC into the following five levels: [1.0, 1.5], (1.5, 2.5], (2.5, 3.5], (3.5, 4.5], and (4.5, 5.0]. Figure 4 presents drivers' takeover time for each combination of pTD and pDC.

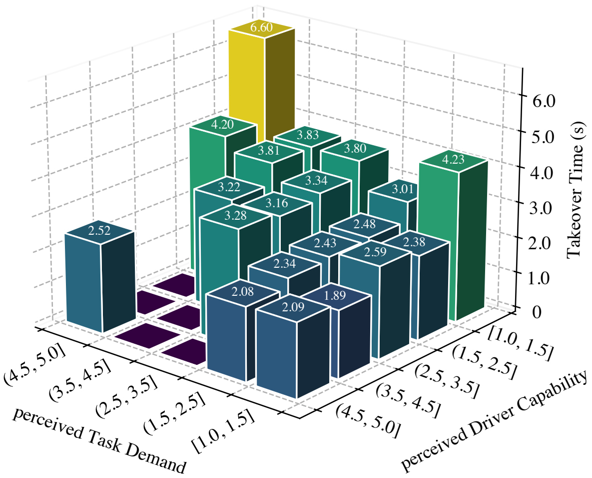

Fig. 4: Drivers' takeover time across their perceived task demands and perceived driver capabilities for takeovers.

Figure 4 illustrates a general positive correlation ($R^2 = 0.72$) between drivers' takeover time and their pTD ($\chi^2(1848, 497) = 2003.02, p < 0.01$), while a general negative correlation ($R^2 = 0.64$) is observed with their pDC ($\chi^2(2926, 497) = 3511.59, p < 0.01$). This observation substantiates our first two hypotheses. When drivers' pDC reaches its highest level, their takeover time exhibits a fluctuating upward trend as pTD increases. This might be because when drivers believe their pDC to fulfil the task is high, they may delay taking immediate control of the vehicle, resulting in longer takeover time. Similarly, a relatively minor fluctuation is observed when drivers' pTD is at its lowest level. We conjecture this is because drivers, under low pTD, have additional attention to monitor driving situations and be prepared to resume vehicle control before receiving takeover requests, leading to shorter takeover time. Meanwhile, when drivers' pTD is at its highest level and their pDC is at its lowest level, there is a notable increase in drivers' takeover time. This implies an amplified joint effect of drivers' pTD and pDC on takeover time. Although the observed takeover time in this scenario can be covered by the provided time budget (7 seconds) or the duration utilized by Mercedes Benz (10 seconds), there is limited time for drivers to execute evasive maneuvers, potentially introducing safety risks. This underscores the importance of offering adaptive time budgets that can be dynamically adjusted according to takeover situations, aligning with findings from [35].

While Figure 4 contains missing values in cases where both drivers' pTD and pDC are low, two explanations for these missing values are conjectured: (i) When drivers' pTD is low, indicating their perception that the takeover task is easy, their pDC tends to be high, and (ii) when drivers' pDC is low, signifying a belief that completing the takeover task is difficult, their pTD tends to be high. These conjectures suggest a potential interplay between drivers' pTD and pDC, requiring further investigation.

This study examines the relationship between drivers' takeover time and their perceived spare capacity (pDC minus pTD). Results are illustrated in Figure 5. A notable decreasing trend is observed in the relationship between drivers' takeover time and their perceived spare capacity ($\chi^2(16478, 497) = 18183.13, p < 0.01$), characterized by a strong exponential correlation ($R^2 = -0.91$). Besides, a substantial reduction in drivers' takeover time is evident at the lowest spare capacity level, while a subtle upward trend is observed at the highest spare capacity level. We posit that this slight increase may be attributed to drivers perceiving the takeover task as challenging (high pTD coupled with low pDC). In this case, drivers tend to heighten their attention to monitor driving situations, preparing to assume vehicle control before takeover requests. In summary, the observed negative relationship between drivers' takeover time and perceived spare capacity aligns with our third hypothesis.

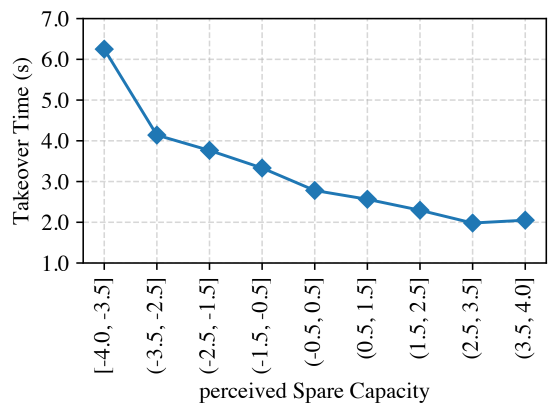

Fig. 5: Drivers' takeover time across perceived spare capacity (perceived driver capability − perceived task demand).

IV. CONCLUSIONS AND LIMITATIONS

This study conducts a driving simulator experiment and a takeover experience questionnaire to examine drivers' takeover time. Results show that drivers can perceive task demand (TD) and driver capability (pDC) correctly. Besides, drivers generally experience longer takeover times when their pTD increases, their pDC decreases, and the perceived spare capacity (i.e., pDC minus pTD) diminishes. Our findings demonstrate the effectiveness of TCI theory in interpreting drivers' takeover time. In addition, we observe that drivers' takeover time fluctuates when their pTD is low or their pDC is high, indicating unstable takeover performance. Notably, when both conditions are met, drivers require significantly more time to take over vehicle control, highlighting the importance of tailoring dynamic time budgets to takeover scenarios rather than relying on fixed time budgets.

This study contributes by (i) conducting takeover experiments and developing scales based on [27]–[30], [32] to measure drivers' pTD and pDC for takeovers, and (ii) providing theoretical guidance for selecting input variables when modelling takeover time through the application of TCI theory, thus enhancing the interpretability of the models. We argue that understanding drivers' takeover time is crucial for optimizing time budgets and designing human-vehicle interactions aligned with drivers' responses, which is essential for enhancing the safety and comfort of takeovers. In our following research, we will explore the role of driver heterogeneity (e.g., age, gender, etc.) in their takeover time.

The experiment in this study was conducted in a driving simulator rather than a real vehicle environment. This may influence participants' responses to takeover requests and compromise the study's external validity. Besides, this study is constrained by its relatively small number of participants. This limitation introduces challenges in validating the developed takeover experience questionnaire and could potentially affect the generalizability and statistical power of the findings. In summary, the transferability of the findings necessitates future validation through a larger and more diverse participant pool andor in on-road settings.

REFERENCES

[1] V. Radhakrishnan, T. Louw, R. C. Gonçalves, G. Torrao, M. G. Lenné, and N. Merat, "Using pupillometry and gaze-based metrics for understanding drivers' mental workload during automated driving," *Transportation research part F: traffic psychology and behaviour*, vol. 94, pp. 254–267, 2023.

[2] C. D. Wickens, R. S. Gutzwiller, and A. Santamaria, "Discrete task switching in overload: A meta-analyses and a model," *International Journal of Human-Computer Studies*, vol. 79, pp. 79–84, 2015.

[3] S. Monsell, "Task switching," *Trends in cognitive sciences*, vol. 7, no. 3, pp. 134–140, 2003.

[4] N. Merat, B. Seppelt, T. Louw, J. Engström, J. D. Lee, E. Johansson, C. A. Green, S. Katazaki, C. Monk, M. Itoh, *et al.*, "The "out-of-the-loop" concept in automated driving: proposed definition, measures and implications," *Cognition, Technology & Work*, vol. 21, pp. 87–98, 2019.

[5] C. D. Mole, O. Lappi, O. Giles, G. Markkula, F. Mars, and R. M. Wilkie, "Getting back into the loop: the perceptual-motor determinants of successful transitions out of automated driving," *Human factors*, vol. 61, no. 7, pp. 1037–1065, 2019.

[6] C. Gold, M. Körber, D. Lechner, and K. Bengler, "Taking over control from highly automated vehicles in complex traffic situations: the role of traffic density," *Human factors*, vol. 58, no. 4, pp. 642–652, 2016.

[7] O. Jarosch, H. Bellem, and K. Bengler, "Effects of task-induced fatigue in prolonged conditional automated driving," *Human factors*, vol. 61, no. 7, pp. 1186–1199, 2019.

[8] Q. Li, L. Hou, Z. Wang, W. Wang, C. Zeng, Q. Yuan, and B. Cheng, "Drivers' visual-distracted take-over performance model and its application on adaptive adjustment of time budget," *Accident Analysis & Prevention*, vol. 154, p. 106099, 2021.

[9] "Road vehicles - Human performance and state in the context of automated driving," International Organization for Standardization, Geneva, CH, Standard ISO/TR 21959:2020, Jan. 2020.

[10] C. Gold, R. Happee, and K. Bengler, "Modeling take-over performance in level 3 conditionally automated vehicles," *Accident Analysis & Prevention*, vol. 116, pp. 3–13, 2018.

[11] C. Gold, D. Damböck, L. Lorenz, and K. Bengler, ""take over!" how long does it take to get the driver back into the loop?" in *Proceedings of the human factors and ergonomics society annual meeting*, vol. 57, no. 1. Sage Publications Sage CA: Los Angeles, CA, 2013, pp. 1938–1942.

[12] G. Huang and B. J. Pitts, "Takeover requests for automated driving: the effects of signal direction, lead time, and modality on takeover performance," *Accident Analysis & Prevention*, vol. 165, p. 106534, 2022.

[13] V. Skrickij, E. Šabanovič, and V. Žuraulis, "Autonomous road vehicles: recent issues and expectations," *IET Intelligent Transport Systems*, vol. 14, no. 6, pp. 471–479, 2020.

[14] G. Lu, J. Zhai, P. Li, F. Chen, and L. Liang, "Measuring drivers' takeover performance in varying levels of automation: Considering the influence of cognitive secondary task," *Transportation research part F: traffic psychology and behaviour*, vol. 82, pp. 96–110, 2021.

[15] A. McKerral, K. Pammer, and C. Gauld, "Supervising the self-driving car: Situation awareness and fatigue during highly automated driving," *Accident Analysis & Prevention*, vol. 187, p. 107068, 2023.

[16] L. Avetisyan, J. Ayoub, and F. Zhou, "Investigating explanations in conditional and highly automated driving: The effects of situation awareness and modality," *Transportation research part F: traffic psychology and behaviour*, vol. 89, pp. 456–466, 2022.

[17] E. Pakdamanian, S. Sheng, S. Baee, S. Heo, S. Kraus, and L. Feng, "Deeptake: Prediction of driver takeover behavior using multimodal data," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 2021, pp. 1–14.

[18] J. Ayoub, N. Du, X. J. Yang, and F. Zhou, "Predicting driver takeover time in conditionally automated driving," *IEEE transactions on intelligent transportation systems*, vol. 23, no. 7, pp. 9580–9589, 2022.

[19] A. D. McDonald, H. Alambeigi, J. Engström, G. Markkula, T. Vogelpohl, J. Dunne, and N. Yuma, "Toward computational simulations of behavior during automated driving takeovers: a review of the empirical and modeling literatures," *Human factors*, vol. 61, no. 4, pp. 642–688, 2019.

[20] R. Fuller, "Driver control theory: From task difficulty homeostasis to risk allostasis," in *Handbook of traffic psychology*. Elsevier, 2011, pp. 13–26.

[21] ——, "The task-capability interface model of the driving process," *Recherche-Transports-Sécurité*, vol. 66, pp. 47–57, 2000.

[22] D. Onate-Vega, O. Oviedo-Trespalacios, and M. J. King, "How drivers adapt their behaviour to changes in task complexity: The role of secondary task demands and road environment factors," *Transportation research part F: traffic psychology and behaviour*, vol. 71, pp. 145–156, 2020.

[23] R. Hoogendoorn, B. van Arem, S. Hoogendoorn, and K. Brookhuis, "Applying the task-capability-interface model to the intelligent driver model in relation to complexity," Tech. Rep., 2013.

[24] R. Fuller, "Towards a general theory of driver behaviour," *Accident analysis & prevention*, vol. 37, no. 3, pp. 461–472, 2005.

[25] M. R. Endsley, "Situation awareness," *Handbook of human factors and ergonomics*, pp. 434–455, 2021.

[26] S. C. Calvert, H. Taale, M. Snelder, and S. P. Hoogendoorn, "Application of advanced sampling for efficient probabilistic traffic modelling," *Transportation research part C: emerging technologies*, vol. 49, pp. 87–102, 2014.

[27] S. G. Hart and L. E. Staveland, "Development of nasa-tlx (task load index): Results of empirical and theoretical research," in *Advances in psychology*. Elsevier, 1988, vol. 52, pp. 139–183.

[28] A. Pauzié, "A method to assess the driver mental workload: The driving activity load index (dali)," *IET Intelligent Transport Systems*, vol. 2, no. 4, pp. 315–322, 2008.

[29] T. Rosenbloom, A. Beigel, A. Perlman, and E. Eldror, "Parental and offspring assessment of driving capability under the influence of drugs or alcohol: Gender and inter-generational differences," *Accident Analysis & Prevention*, vol. 42, no. 6, pp. 2125–2131, 2010.

[30] T. Lajunen and H. Summala, "Driving experience, personality, and skill and safety-motive dimensions in drivers' self-assessments," *Personality and individual differences*, vol. 19, no. 3, pp. 307–318, 1995.

[31] L. M. Martinussen, M. Møller, and C. G. Prato, "Assessing the relationship between the driver behavior questionnaire and the driver skill inventory: Revealing sub-groups of drivers," *Transportation research part F: traffic psychology and behaviour*, vol. 26, pp. 82–91, 2014.

[32] B. Zhang, J. De Winter, S. Varotto, R. Happee, and M. Martens, "Determinants of take-over time from automated driving: A meta-analysis of 129 studies," *Transportation research part F: traffic psychology and behaviour*, vol. 64, pp. 285–307, 2019.

[33] S. Li, P. Blythe, W. Guo, and A. Namdeo, "Investigating the effects of age and disengagement in driving on driver's takeover control performance in highly automated vehicles," *Transportation planning and technology*, vol. 42, no. 5, pp. 470–497, 2019.

[34] S. G. Hart, "Nasa-task load index (nasa-tlx); 20 years later," in *Proceedings of the human factors and ergonomics society annual meeting*, vol. 50, no. 9. Sage publications Sage CA: Los Angeles, CA, 2006, pp. 904–908.

[35] K. Liang, S. C. Calvert, and H. van Lint, "Sufficient time budgets for safe and comfortable control transitions: A systematic review," *Available at SSRN 4518331*.