Understanding Drivers' Takeover Time: Insights from the Task-Capability Interface (TCI) Theory

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Abstract

Conditionally automated driving implies a paradigm shift: drivers can engage in non-driving related activities, while they have to respond to objects and events in the environments and take over vehicle control when requested by automation. Such requests for takeovers can impose significant cognitive demands on drivers, especially when drivers are disengaged from the driving process. This may escalate the risk of collisions if drivers do not manage to safely resume manual control within a limited time budget. One potential solution to ensure safe and comfortable takeovers is to provide sufficient time budgets that allow drivers the necessary duration to regain vehicle control securely. Determining such sufficient time budgets relies on comprehending and forecasting drivers' takeover time, i.e., the duration required for drivers to resume conscious control of the vehicle. This is an aspect that remains underexplored and constitutes the central focus of this study.

This study aims to interpret the determination of drivers' takeover time based on the Task-Capability Interface (TCI) theory. A hypothesis is constructed as "Drivers adjust their takeover behaviours based on the dynamic interactions between their perceived takeover task demands and perceived driver takeover capabilities, which accordingly results in various takeover times." To validate this hypothesis, we conducted a driving simulator experiment where drivers encountered nine takeover scenarios (3 traffic densities $\times$ 3 non-driving related tasks). This design aims to vary the levels of takeover task demands and driver takeover capabilities. Besides, we measured drivers' perceived demand and perceived capability to fulfil takeover tasks after each scenario. This questionnaire was based on well-established instruments (including the NASA Task Load Index, Driving Activity Load Index and Driver Skill Inventory) and was carefully modified for takeover contexts. On this basis, we investigated the relationship between these two constructs and the takeover time that drivers require to resume conscious vehicle control safely (i.e., does not cause any accidental harm) and comfortably (i.e., does not elicit any sensation of unease or discomfort). The understanding of such a relationship can facilitate the development of a predictive model for drivers' required takeover time and then help to determine sufficient time budgets for safe and comfortable takeovers.

In conclusion, this study's targeted contributions encompass (i) the modification of scales to measure perceived takeover task demands and driver takeover capabilities, (ii) the proposition of required takeover time which plays a fundamental role in determining sufficient time budgets, and (iii) the interpretation of drivers' takeover time based on the TCI theory. This holistic understanding of driver takeover time enables the development of strategies to minimize potential risks associated with takeovers. Such knowledge can also facilitate the design of human-vehicle interactions that align with drivers' cognitive and physiological responses. These aspects are essential to enhancing the safety and comfort of takeovers, thereby boosting acceptance of conditionally automated driving.