Impact of drivers' take-over manoeuvres on automated vehicles' traffic flow dynamics

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1 INTRODUCTION

Background

Until automated vehicles (AVs) can fully handle all driving tasks in every condition, drivers must intervene when these systems fail or exceed their operational limits. At higher automation levels (SAE L3 and L4), drivers can perform non-driving tasks while the system monitors the environment and alerts the driver to take over when needed. In such cases, important questions arise about how long it takes for drivers to reclaim manual control, what factors determine takeover time, and the consequences of increased takeover time and poor takeover performance are.

Literature review

(a) Human factors underlying drivers' takeover performance

Studies focusing on drivers' takeover time and performance have consistently indicated that factors such as traffic conditions, the criticality of the situation, driver distraction, and engagement in handheld tasks significantly affect drivers' takeover time and performance in automated vehicles (see, for example, Zhang et al., 2019, for a comprehensive review and meta-analysis). For instance, more urgent situations and prior experience lead to quicker responses, while engaging in non-driving tasks, especially with hand-held devices and increased mental workload, affects individuals variably, depending on psychological factors such as subjective risk perception and alertness.

(b) Consequences of driver's takeover performance

Numerous studies have investigated the consequences of drivers' takeover time and performance, with the majority focusing on the safety of the subject vehicle. The findings generally reveal that longer takeover times and the quality of the takeover—marked by factors such as braking intensity and lane deviation—can increase crash risks. The observed effects heavily depend on factors like time-headway, the driver's psychological state, and their engagement in handheld non-driving tasks (e.g., He et al., 2022; Lin et al., 2020; Pipkorn et al., 2022). These findings suggest that the combined impact of human psychological factors and traffic conditions might be the root cause of consequences of drivers' take-over interventions for the subject vehicles.

Similarly, it's imperative to acknowledge the ripple effects of these interventions on the traffic behind, especially if the following vehicles are AVs following a cooperative driving strategy with the subject vehicle . Beyond the immediate safety concerns for the subject vehicle, such interventions can disrupt traffic flow, initiating traffic shockwaves or imposing destabilizing effects. The extent of these effects may be influenced by the combined interactions between traffic conditions, human psychological factors, and the control strategy of the following AVs.

Research Gaps

The existing literature on this topic is limited, primarily focusing on the impact of takeover maneuvers on the subject vehicle, particularly on aspects such as increased time-headways (see, e.g., Varotto et al, 2015). A crucial research gap exists in understanding how human driver takeover maneuvers in autonomous vehicles (AVs) impact subsequent traffic flow dynamics, arising from the complex experimental design, which requires considering multiple factors, including varied traffic scenarios, human psychology, and the unknown underlying control mechanisms in commercial AVs, integrating mentally engaging tasks before takeover requests raises safety concerns in field experiments.

Objective and Contributions:

To bridge the gap, we conducted a comprehensive, reproducible driving simulator experiment, placing human factors and AVs at the forefront. This enabled us to investigate critical questions regarding the dynamics between driver takeover maneuvers and the subsequent AVs' traffic flow dynamics.

The objective of this study is to quantitatively evaluate the impact of driver takeover maneuvers, following engagement in non-driving tasks, on the traffic flow dynamics of subsequent autonomous vehicles, using a comprehensive driving simulator experiment. The contributions of this study are multi-fold and include revealing answers to several critical questions:

- Whether such takeover maneuvers, occurring after drivers' engagement in non-driving tasks, exert a meaningful impact on the subsequent AVs' traffic flow.
- If so, whether the observed effects—whether positive or negative—are statistically significant after controlling for all other interacting factors.
- Whether these effects can be meaningfully ascribed to underlying psychological factors.

2 Experimental study design: Comprehensive driving simulator experiment

Previous studies primarily examined drivers' interactions with AVs regarding takeover time, performance, and the subject vehicle's consequences. This experiment shifts focus to explore how these interactions might impact traffic flow of surrounding and subsequent AVs. This central question guides all aspects of our study, from hypothesis construction to technical implementations and participant invitation protocols. The central hypothesis in our design are:

Hypothesis 1 *Drivers' take-over performance is influenced by traffic conditions, previous engagement in non-driving tasks, and individual psychological factors, leading to variations across participants.*

Hypothesis 2 *The impact of drivers' takeover maneuvers on following AVs depends on drivers' takeover performance, traffic conditions, and the AVs' longitudinal controllers.*

Hypothesis 3 *After controlling for all other interacting factors, psychological factors might emerge as the primary determinant of the impacts of driver takeover maneuvers on AVs' traffic flow dynamics.*

In the following, we briefly discuss the experiment, primarily focusing on the takeover scenario, while omitting some essential details due to space constraints. Three scenarios were conducted in this experiment In each scenario, participants were asked to drive through a route consisting of two 4-lane motorways connected to each other for roughly 25 minutes. On each motorway, participants merged into the motorway and interacted with surrounding vehicles, experiencing a complete traffic regime identical on both freeways in terms of layout and traffic conditions, except for the speed limit. Participants initially encountered stop-and-go conditions generated from NGSIM vehicle trajectories for two rows of lead vehicles. After this phase, the lead vehicles' controllers transitioned to autonomous mode, accelerating to maintain a desired speed. This established a scenario of steady-state driving lasting approximately 10 minutes. In the first scenario, participants solely performed this phase in human-driving mode. However, in scenarios 2 and 3, participants were prompted with an auditory message at the end of the stop-and-go phase, instructing them to activate the auto-driving mode by pressing a button. In scenario 2, participants are engaged in SAE Level 4 automation, where they are asked to complete riddles using pen and paper. In Scenario 3, participants are involved in SAE Level 3 automation, where they are asked to pay attention to the road. At the end of the steady-state phase, when the participant's vehicle approaches a stationary AV within a consistent distance (uniform across all roads and scenarios), the stationary AV starts moving. This action causes the two lead vehicles of the participants to slow down, while the participant's vehicle maintains a steady-state condition. This setup aims to examine participant responses across three distinct scenarios outlined in Table 2.1.

Table 2.1 – *Description of the three different scenarios during steady-state driving. All the instructions were presented to the participants through auditory message*

Scenario	**Steady-state performed by**	**Participant's Task**	**Stimulus**
Scenario 1	human driver	NA	Participant's sensation
Scenario 2	auto-driving mode	Complete engaging riddles	System's request
Scenario 3	auto-driving mode	Eyes on the road	System's request

3 Completed work and preliminary results

This section briefly mentions the completed and ongoing work and some preliminary results.

- **Completed Work**
  - Experiment concluded; all participants invited and data extracted. Our driving simulator experiment stands out for its rigorous participant protocols and comprehensive, diverse sample across various age and gender groups as illustrated in Figure 3.1

– Preprocessed participant data matched with CAV data; cleaned and categorized experiment task data. Analyzed pre-experiment questionnaire data; constructed driver profiles.

- **Preliminary results**

  We present preliminary results from our analysis of vehicle trajectories in the takeover scenario, illustrated in Figure 3.2, aligning with our hypothesis. Situation (a) shows prolonged takeover times causing severe participant reactions, leading to complete stop-and-go phases in subsequent AV behavior. Conversely, situation (b) demonstrates manageable takeover times, resulting in less intense participant reactions and subsequent AV behavior.

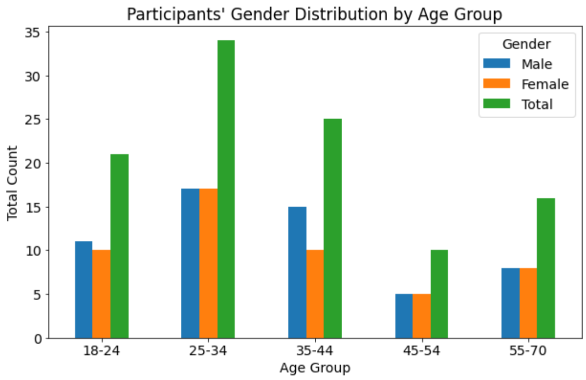

Figure 3.1 – *Wide age-gender distributions of the sample size of the participants invited in our driving simulator study*

(a) (b)

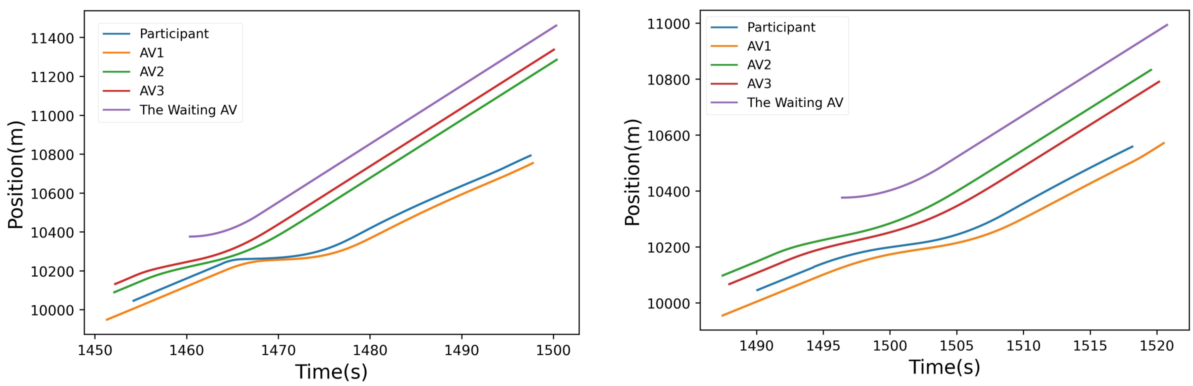

Figure 3.2 – *Sample trajectories of the participants and AVs before, during, and after participants' takeover in scenario 2: A situation in which the participant's takeover time is massively increased and the participant reacts severely, causing a complete stop-and-go phase in its subsequent AV (a). A situation in which the participant's takeover time is manageable, resulting in a much less intense wave in its subsequent AV (b).*

4 Ongoing work

– Analyzing data for driver takeover time across scenarios, including constructing human factor profiles and investigating drivers' response in three scenarios;

– Investigating impacts on subsequent AVs.

5 Selected references

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