Requirements for safe and satisfactory use of partially automated driving systems in urban environments: An expert field study

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Abstract: In response to the growing trend of automation on German roads, this expert test explores the challenges of implementing partially automated driving systems in urban environments. Drawing on the experiences of Human factors experts, the research explores user preferences across diverse traffic scenarios, utilizing the Tesla Full Self-Driving System (FSD). The analysis identifies critical requirements, emphasizing the importance of reliable system functionality. Despite an initial decline in user acceptance, the study suggests potential user adaptation in trust and acceptance, indicating a positive evolution with prolonged system use but also raising concerns about an increased propensity for system misuse.

Keywords: Acceptance, Urban Automated Driving, Adaptation, Misuse

1. Introduction

The increasing extent of automation on German roads is a constant trend. With driving functions of automation Level 2 (L2, partially automated) as defined by the Society of Automotive Engineers, the automated driving system takes over the longitudinal and lateral control of the vehicle. At the same time, the driver remains in charge of monitoring and is responsible for the driving behavior (SAE International 2021). Although L2 functions are already in use on German roads, they are currently limited to specific scenarios (e.g., Tesla; 2023). The large-scale introduction of these systems in urban environments as an operational design domain (ODD) is facing some challenges. The system must be safe in the city and be acceptable by providing a recognizable benefit for users, such as a reduced workload or increased safety or comfort. However, studies show that currently available functions in the urban environment can even increase the driver's workload compared to manual driving (Kim et al. 2023). Driver workload and the system's safety are, in turn, influenced by the driving environment and the impact arising from the system's characteristics (Kim et al. 2023; Othersen, 2016). This raises two questions: under which conditions does the use of L2 functions satisfy users, and how safe the use of an L2 system is in various urban scenarios and ODDs.

To answer these questions, this study aims to gain insight into the experience of L2 driving in different scenarios. Therefore, it is explored in which scenarios the use of L2 systems in the city is safe and satisfying. One goal is to determine the requirements for the scenario and identify the scenario factors that users perceive as particularly positive or negative. Another goal is to investigate which (possibly scenario-dependent) requirements exist regarding the automation. To comprehend longitudinal changes in these requirements, the study will evaluate the influence of the test drive on acceptance and trust into the system, focusing on expected user adaptation effects.

2. Materials and Methods

The data was collected as part of an expert field test using a Tesla Model Y with the latest software version approved in Germany (Version 2023.26.9). The vehicle was equipped with Tesla's partially automated driving System, referred to as the Tesla Full Self-Driving System (FSD). The system was selected for the test drives because, at the time of data collection, it was one of the L2 serial systems with the most advanced system functions for inner-city use. In particular, the system includes a traffic light and traffic sign assistant. Nevertheless, it should be noted that the FSD and comparable systems are not explicitly dedicated to urban use (Tesla 2023).

2.1 Test Procedure

The study was conducted as part of a 45-minute drive with human factors experts (N = 10) in the Munich area. It covered highway, rural, and various urban scenarios, such as intersections, ring and main roads, crosswalks, roundabouts, and residential areas. The test procedure involved a brief system introduction, a written pre-survey, an oral semi-structured interview conducted during the drive, and a written post-survey.

Acceptance and trust in automation were measured through the acceptance questionnaire by van der Laan (1997) and selected items from the Trust in Automation questionnaire (TiA) by Körber (2019). Only TiA items contributing to subscales, where an influence through the system experience could be expected and answered based on user assessment before interacting with the system, were utilized. This approach considered the subscales of *reliability/competence* and *trust in automation*.

The semi-structured interview addressed factors influencing acceptance and trust, perceived safety, potential system misuse, and adaptation effects. Specific items emphasizing differences between the three driving environments were reiterated across all environments. Tab. 1 provides a list of the interview items.

Table 1: *Items of the semi-structured Interview in English (translated version)*

ID	Environment	Translated Item (English)
1	Urban	In which situations/scenarios in the urban environment would you not like to use the FSD system in the future?
2	Urban	In which situations/scenarios in the urban environment would you like to use the FSD system in the future?
3	Urban	Under what conditions would you rather use the system in the urban environment?
4	Urban, Rural, Highway	In this driving environment, what are the reasons why you distrust the system or feel unsafe?
5	Urban, Rural, Highway	Can you imagine the system leading to system misuse/abuse in this driving environment?
6	No specific environment	What changes in your attitude towards the system and in your driving/usage behavior would you expect with long-term system use?

2.2 Data Analysis

The collected quantitative data were analysed using the software RStudio. Excel was used to document and structure the qualitative data obtained from the interviews. Therefore, similar statements were collated, summarized, and structured by frequency for analysis.

3. Results

3.2 Interview Data

In response to the interview item with ID 1 the experts answered most frequently (n = 4) with busy intersections. Additionally, three participants responded with situations requiring driving close to static objects (e.g., parked vehicles on the roadside), narrow roads in general, and when the road is located in residential areas. Two participants mentioned many vulnerable road users (VRUs) as a factor of a situation in which the system would preferably not be used. In relation to the inquiry with ID 2, participants predominantly expressed their preference for utilizing the FSD system on main roads. Specifically, the urban ring road was mentioned by most of the participants (n = 7), while five participants indicated a preference for using the system on wide/multi-lane roads. Furthermore, two respondents mentioned they prefer the FSD system in traffic jam situations. Respondents favored specific conditions for deploying the system in urban environments, as indicated by the responses to the interview question with ID 3. A more anticipatory driving style (n = 3) and a more natural driving style (n = 2) were highlighted. Additionally, enhanced Human-Machine Interface (HMI) interpretability, mitigating Mode-Confusion (n = 3), and improved HMI visibility (n = 2) emerged as key preferences. As general factors contributing to distrust and uncertainty in urban environments (item with ID 4), six respondents reported experiencing system errors, with four instances of phantom braking and three errors related to traffic light detection. High traffic volume, including VRUs, was mentioned by six participants. Additionally, five respondents expressed concerns about proximity to other road users and static objects, requiring immediate reaction times. Three participants also highlighted discomfort with the system's unnatural driving behavior, while two participants identified issues of system opacity, and two participants mentioned complex lane markings as a reason. Furthermore, two respondents noted unreliable object detection in oncoming traffic and a lack of trust in other road users as contributing to overall distrust and uncertainty. For the same question in rural environments, three respondents reported system errors, and two mentioned their inexperience with the system. Five participants reported system errors on highways, four incidents during automated lane changes, and two cited inexperience with the system. When asked whether the system was likely to be misused in the future in the respective driving environment (Item with ID 5), the participants gave varying answers, with the overall tendency towards system misuse being lower in the city than on rural roads or highways (see Fig. 1). In addition, all those who predicted misuse in the city indicated restrictions such as "only on highway-like roads", "only in low traffic volume" or “only at traffic light intersections”. In contrast, no further restrictions other than experience with the system were made in the other driving environments.

In response to the Item with ID 6, the experts anticipated changes in attitudes with prolonged system use, such as selective system (de)activation (n = 6). Five participants raised concerns about an increasing tendency to system misuse depending on experience. Furthermore, higher willingness for system use was expected (n = 4), as well as increased trust and acceptance in scenarios where positive experiences were made (n = 3), contributing to an overall rise in usage comfort.

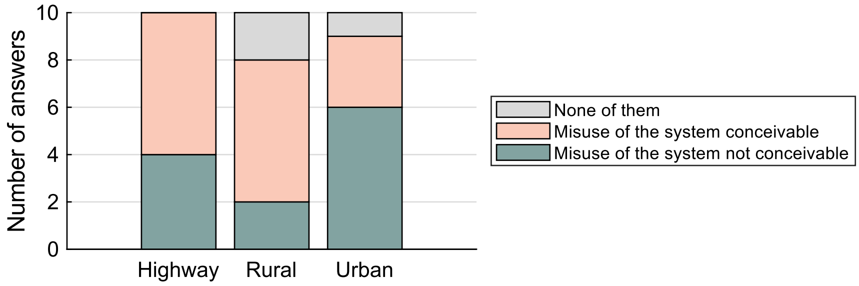

***Figure 1**:* *Interview responses on the conceivability of misuse of the partially automated driving system in the three environments examined: highway, rural road, and urban environment.*

3.2 Questionnaire Data

The questionnaire results were examined for group differences before and after the drive using the recorded subscales. For each construct (trust and acceptance), a univariate repeated measures MANOVA was conducted. The results show non-significant differences on the subscales related to trust in automation (*$F(2, 13) = 0.525$, $p = 0.604$, pillai's trace = 0.075*). Therefore, no influence of the test drive on trust is assumed. On the other hand, the two subscales recorded by the acceptance questionnaire following van der Laan (1997) exhibit significant differences before and after the test drive (*$F(2, 15) = 4.491$, $p = 0.030$, pillai's trace = 0.375*) suggesting a decrease in acceptance between measurement points. A descriptive data presentation is available in Fig. 2.

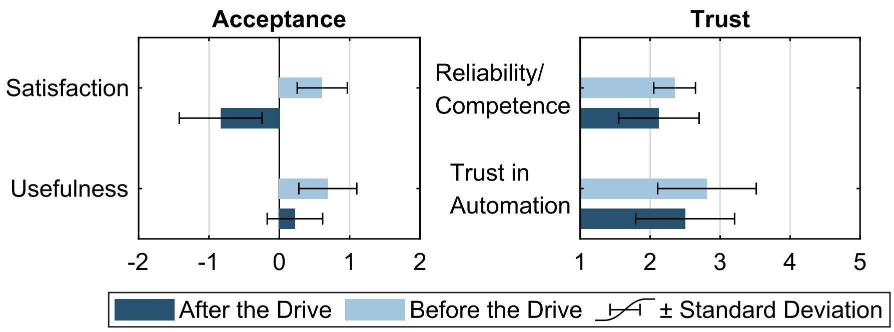

***Figure 2**:* *Ratings of system acceptance (N = 9) and user trust (N = 8) separated into their respective subscales before and after the test drive.*

4. Discussion

4.1 Aggregated Requirements

The obtained data was translated into requirements for urban use and subsequently clustered into three categories: requirements for the system functions, for the driver-vehicle interaction, and for the scenario (see Tab. 2). It is noteworthy that the requirements were generated not only from the statements reported in Section 3.1 but also from statements provided by individual participants (n = 1). It should be emphasized that the requirements for the technical system and deployment scenarios must be considered interconnected, influencing each other.

Table 2: *Aggregated requirements for urban use of partially automated driving systems derived from the interview data, categorized into system functions, driver-vehicle interaction, and scenario.*

Requirements for the system functions	**Requirements for the driver-vehicle interaction**	**Requirements for the scenario**
• Reliable traffic light detection • Reliable detection of oncoming traffic • Reliable recognition of traffic signs • Reliable pedestrian detection • Reliable emergency braking function • Natural driving behavior • Low overall error rate • Anticipatory driving style • High availability (large operational design domain)	• No system-induced changes in automation level • Visibility of the HMI (Human-Machine Interface) • System transparency • Comprehensibility of the HMI • Warning in case of system disengagement or system-initiated transition • Driver monitoring system that warns in case of driver inattention	• Clear view • Broad road • Simple lane guidance • Well-defined road markings • Steady speed limit • No turning intentions of the ego vehicle • No lane-changing intentions of the ego vehicle • Low traffic volume • Predictable behavior of other road users • No VRUs in the vicinity of the vehicle • No crossing VRUs

4.2 Adaptation Processes

The observed decline in user acceptance after the initial FSD experience contrasts with responses to Question ID 6, where users expressed increased acceptance with growing system familiarity. This suggests a potential adaptation curve, initially influenced by potentially unmet expectations in the first place but evolving positively with an enhanced understanding of system behavior and capabilities in the long run. Despite non-significant drops in trust levels after the 45-minute drive, descriptive data indicate a subtle decline. User statements and the inclination towards system misuse align with the expectation of increased trust with prolonged system use, given the potential risk of misuse due to overtrust (Lee & See 2004), emphasizing the significance of long-term analysis in urban environments. Although experts consider misuse in urban scenarios less likely than in other environments, it cannot be ruled out, especially considering potential adaptation effects over the duration of system availability. Given the proximity to other road users, static obstacles, and increased presence of VRUs, misuse is deemed highly critical in urban scenarios. Furthermore, the impact of key events on scenario experiences is noteworthy. System errors often caused uncertainty or distrust among participants, anticipating decreased system usage in encountered scenarios. A detailed examination of how these events influence adaptation curves necessitates further investigation. Additionally, it remains unclear whether users prefer the use of the FSD system on main roads, especially the urban ring road, due to habituation effects or whether, in the long run, their preference is influenced by positive experiences with the system in urban scenarios.

4.3 Further Limitations

Notably, the subjective nature of the data collection process and the fact that the perspectives offered by experts may not comprehensively represent the viewpoints of the actual users of the automated driving system. However, it is crucial to highlight that the requirements were gathered using a system not dedicated to urban environments, thus influenced by system errors and weaknesses. Therefore, a more comprehensive exploration across various automated driving systems is required.

5. Conclusion

Key findings include the importance of reliable system functions, users' preferences for major roads, and concerns about system errors impacting trust. Despite an initial drop in acceptance, the experts expected positive user adaptation effects with prolonged use especially on motorways. Misuse behavior, in particular, should be examined more closely in this context. Although misuse is little expected by the experts, increased trust with greater system experience or a more reliable system can encourage misuse. The high criticality of misuse in urban environments requires adequate driver monitoring. The aggregated requirements can serve as both enablers by establishing conditions for system use and supporters, enhancing utilization frequency and satisfaction. However, the research highlights the need for ongoing analysis to advance automated driving technologies in urban environments.

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