Design Recommendations for Operation Center HMIs in Automated Fleet Operations: A Field Study from the Campus FreeCity Project

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Summary: This study evaluates the HMIs developed for the operation center of the CityBot as part of the BMDV-funded Campus FreeCity project. The dispatcher and remote operator HMIs were assessed in a field study to determine acceptance, perceived control and safety, workload, usability, and immersiveness. Standardized questionnaires and interviews were employed to gather data from 20 participants with minimal experience in remote operation technologies. Results for the dispatcher HMI indicated high acceptance, good usability, and low to moderate workload, with participants appreciating the overview map and color-coded vehicle status indicators. Suggestions for improvement included better error message handling, enhanced live video feeds, and shortcut functions to reduce user effort. For the remote operator HMI, acceptance and usability ratings were moderate, with higher workload compared to the dispatcher role. Participants highlighted challenges in vehicle control and spatial awareness. Recommendations included augmented reality features and additional auditory feedback to improve navigation.

1 Introduction and Research Objective

SAE Level 4 automated vehicles will no longer be required to have an on-board operator [15]. Instead a technical supervisor in an operation center is monitoring [2] and coordinating [1] the vehicles. When the vehicles reach their operational limits the technical supervisor is further responsible for evaluating and releasing or deactivating driving maneuvers proposed by the vehicle [17] or for taking control of it to circumnavigate obstacles [1]. Additionally, the technical supervisor is tasked with communicating with authorities, passengers and other road users [10].

It is therefore imperative that the human-machine interface (HMI) of the operation center is designed in a manner that facilitates the efficient fulfilment of tasks. In order to achieve this, the HMIs must guarantee safe and intuitive operation, offer a high level of usability, and reduce the workload of the technical supervisor.

Accordingly, the following requirements have been postulated in previous studies. An overview should be capable of displaying the location, charge status, operating status, and current and pending orders of the vehicles in real time [10, 11]. In the event of malfunctions

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that require action, it is essential that acoustic and visual warning signals be provided, accompanied by concrete support suggestions for solving the problem [11, 18]. Moreover, live video transmissions of the vehicles and a representation of the relevant infrastructure should be accessible [10, 11]. In particular, for remote operation, the provision of a visual representation of the forces exerted on the pedals and the acceleration forces affecting the passengers is considered to be of significant benefit [18]. The projection of the future vehicle trajectory or the color coding of depths in the camera image can further facilitate control [18, 3]. Moreover, information regarding applicable traffic regulations should be incorporated [18]. Furthermore, a virtual overlay of the vehicle body within the video image offers an additional source of orientation [8].

In previous studies, the HMIs designed for the operation center were evaluated through the use of click dummies [10, 11], in simulated environments [16, 3, 8], or via remote operated driving on test tracks utilising either small robot vehicles [9] or automated vehicles [18]. However, there has been a lack of evaluations in actual field settings.

As part of the BMDV-funded project Campus FreeCity, the HMIs for the operation center of the CityBot were developed following the human-centered design process [4]. A context of use analysis was conducted based on a systematic literature review and expert workshops, resulting in the definition of the tasks to be performed by operation center personnel [17]. Subsequently, the roles within the operation center were delineated into dispatchers and remote operators, accompanied by a detailed workflow definition [17, 14].

In the case of the CityBot operation center, it was determined that the dispatcher bears the responsibility for monitoring and coordinating the vehicle fleet. When a vehicle is approaching its operational limits, the dispatcher is responsible for evaluating proposed maneuvers and approving or deactivating them. In the event that a vehicle requires further intervention, the dispatcher forwards the request to the remote operator while notifying pertinent stakeholders, including other vehicles in the fleet, passengers, pedestrians, and authorities. The remote operator subsequently assumes direct control of the vehicle, utilizing steering wheel and pedal inputs and also communicates with relevant stakeholders.

Based on this role distribution, specific requirements for the HMIs were determined and subsequently implemented by EDAG PS as well as T-Systems in an iterative development process. The resulting HMI designs are presented in figure 1. Instructions for the dispatcher HMI can also be accessed via the following DOI: https://doi.org/10.48328/tudatalib-1589.3 .

Figure 1: Dispatcher HMI (left, copyright 2024 EDAG Group) and remote operator HMI (middle, copyright 2024 T-Systems) for the operation center of the CityBot (right, copyright 2023 EDAG Group)

The objective of the field study presented in this paper is to evaluate the HMIs developed for the dispatcher and remote operator for the operation center of the CityBot. In particular, the study will assess the acceptance, perceived control and safety, workload, usability, and immersiveness of the HMIs, in order to identify potential for optimization.

2 Methodology

The following outlines the methodology used to address the research objective and quantify the dependent variables acceptance, perceived control and safety, workload, usability and immersiveness. Further, the study procedure as well as the participants are described.

2.1 Dependent Variables

For both HMIs acceptance was evaluated using the questionnaire according to van der Laan et al. [19]. It contains 9 items which are rated on a 7-point Likert scale and summarized into the scales usefulness and satisfaction. Perceived control and safety were each measured using an 11-point Likert scale, based on the methodology described by Chucholowski et al. [3]. Workload was assessed using the NASA Task Load Index [7], which contains 6 items that are rated on a scale from 0 to 20 and combined into an overall score using weighted values. Usability was evaluated using the Post-Study System Usability Questionnaire [12]. It contains 17 items that are rated on a 7-point Likert scale, which are distributed across the scales of information quality, interface quality and system quality and can be combined into an overall rating. For the remote operator HMI immersiveness was measured based on the methodology described by George et al. [6]. The questionnaire consisted of ten items, including lateral distance classification, longitudinal distance classification, trust in the system, responsiveness of the system, interaction with the environment, perception of reality, overview of the environment, system handling, intuitiveness, and controllability. Each item was rated on a 9-point Likert scale.

2.2 Procedure

The evaluation of the HMIs for the dispatcher and remote operator was conducted as a two-hour field study at Deutsche Bank Park in Frankfurt, Germany. At the outset of the study, the participants were provided with a comprehensive overview of the Campus FreeCity research project and the study procedure. The study's objectives and the specific procedure were presented in detail. Subsequently, the participants were required to sign the information sheet, the declaration on data protection, and the declaration of consent for audio recording.

The practical testing phase commenced with a comprehensive briefing on the operational procedures associated with the workstation for the dispatcher or remote operator role. In their role as a dispatcher, the participants were required to perform a series of tasks, including the blocking and releasing of routes, the rescheduling and releasing of trips, the analysis of completed trips, the identification of obstacles, and the validation and release of proposed driving maneuvers. In the case of the remote operator role, the test subjects assumed control of the CityBot via teleoperation, specifically in navigating around an obstacle positioned on the road via the use of a steering wheel and pedals.

Subsequently, the participants completed the standardized questionnaires described above, which assessed their acceptance, perceived control and safety, workload, usability, and immersiveness. Subsequently, a qualitative interview was conducted with the test subjects, who were asked to identify potential areas for improvement with regard to the HMIs of the dispatcher and remote operator. The study was concluded with a debriefing, during which remaining questions from the participants were answered and final feedback was obtained. The structured course of the study enabled the systematic and well-founded collection of both quantitative and qualitative data.

2.3 Participants

The participants were selected from an existing pool of participants from the Institute of Human Factors and Ergonomics at TU Darmstadt. A valid driver's license was a prerequisite for participation. The dispatcher HMI was evaluated by 12 participants (age range: 21-65, 8 males, 4 females) who, for the most part, lacked experience with video games and drone control. The remote operator HMI was evaluated by 8 participants (age range: 23-65, 6 males, 2 females) who also exhibited minimal experience with video games and drone control. As a consequence of technical difficulties, six of the eight participants were only able to complete sections of the task designated for the remote operator. The characteristics of the participants are presented in figure 2.

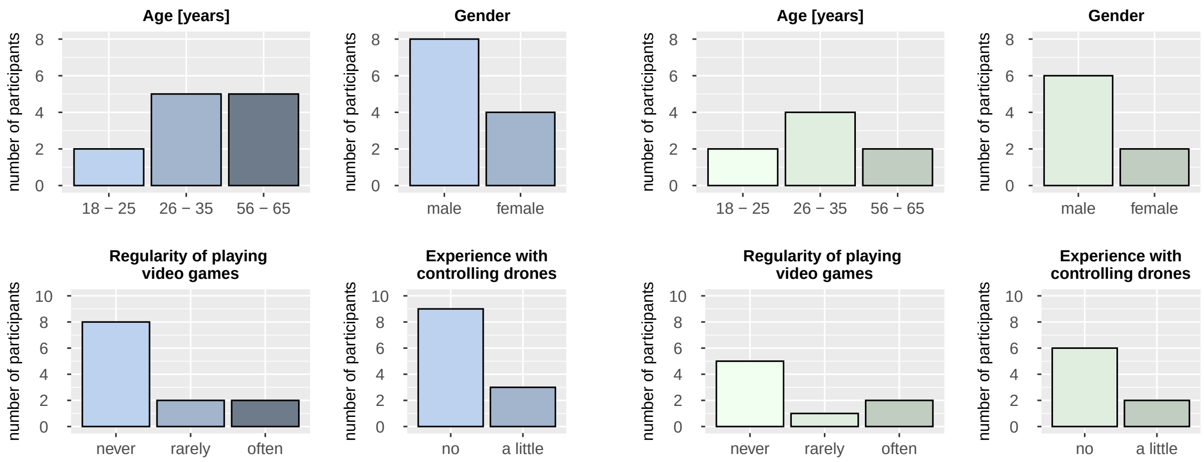

Figure 2: Participant characteristics for the evaluation of the dispatcher HMI (n=12, blue) and the remote operator HMI (n=8, green)

3 Results

The questionnaires were evaluated in accordance with the specifications outlined in the respective papers. Due to the restricted sample size, the data were subjected to descriptive analysis. The interview data were transcribed and subjected to analysis in accordance with the descriptive qualitative data analysis method proposed by Mayring [13]. The data can be accessed via the following DOI: https://doi.org/10.48328/tudatalib-1589.3 . The results for the dispatcher and remote operator HMI are presented separately in the following sections.

3.1 Dispatcher HMI

The results for the dispatcher HMI are presented in figure 3. The acceptance rating was positive, with participants indicating that they found the HMI useful (Md = 6.3, min = 4.6, max = 7.0) and satisfactory (Md = 6.4, min = 4.0, max = 7.0). The perceived control was generally evaluated in a positive manner (Md = 8.0, min = 4.0, max = 10.0), while the perceived safety was rated somewhat lower, but still within the positive range (Md = 8.0, min = 4.0, max = 10.0). The workload for the dispatcher HMI was rated as low to moderate (Md = 7.4, min = 3.0, max = 12.5). The overall usability, as well as all three scales, was rated as rather good (total: Md = 5.3, min = 4.6, max = 6.7; information quality: Md = 5.0, min = 4.2, max = 6.6; interface quality: Md = 6.0, min = 4.0, max = 7.0; system quality: Md = 5.4, min = 4.8, max = 6.8).

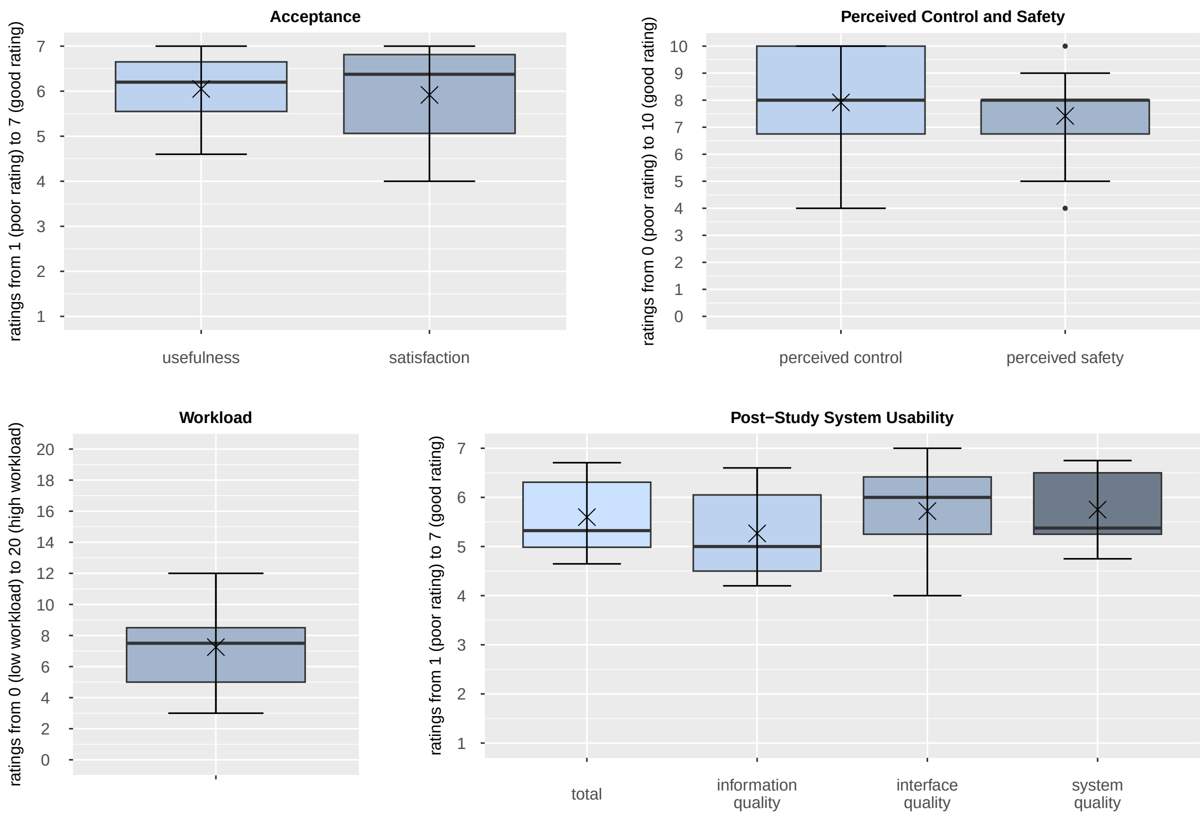

Figure 3: Results for acceptance, perceived control and safety, workload and usability for the dispatcher HMI (n=12).

The analysis of the interview data revealed several optimization potentials for the dispatcher's HMI. In particular, the design of the comprehensive overview map, the display of error messages, and the integration of real-time video feeds were identified as pivotal areas for enhancement.

The overview map (see figure 1), which provides a visual representation of the operational area, including all routes and CityBots, was perceived as a highly beneficial tool by the participants. The color coding, which indicates the status of the vehicles, was particularly well received. To further enhance the visibility of vehicles with error messages that require immediate attention, it was proposed that a high-frequency flashing be integrated in addition to the existing red color coding. Furthermore, a menu should be displayed upon hovering the cursor over a vehicle, providing comprehensive information such as the vehicle's name, current configuration, current order, battery status, and any associated error messages. Furthermore, an additional option should be made available for editing the vehicle directly by right-clicking on the vehicle, in addition to the existing menu on the left-hand side. This additional menu navigation could assist in reducing the number of mouse and eye movements, which would otherwise be excessive when working with a large monitor. Conversely, it was observed that the presence of superfluous menus might prove to be a hindrance to the system's learnability.

The participants found the current display of error messages to be an irritating distraction, as it has the tendency to overlay the view and disrupt the workflow. As indicated by the respondents, this frequently results in acknowledgment and potential neglect of the error messages. The proposed solution was to display the error messages in a distinct area at the periphery of the map. Such messages could be listed in the order of occurrence and processed in a systematic manner. In contrast, error messages resulting from incorrect operation of the HMI should be presented as pop-up windows that automatically close, thus avoiding unnecessary disruption to the user.

Furthermore, the live streams present potential avenues for enhancement. The respondents expressed a desire to be able to adjust the size and position of the live stream images on an individual basis. Additionally, it was noted that the ability to control the cameras, for instance through zoom functions, could markedly enhance the usability of the system.

In addition to the aforementioned measures, the introduction of shortcut functions could further optimize the usability of the dispatcher HMI and increase the efficiency of work processes.

3.2 Remote Operator HMI

The results for the dispatcher HMI are presented in figure 4. The acceptance rating was positive, with participants indicating that they found the HMI useful (Md = 6.2, min = 4.6, max = 7.0) and satisfactory (Md = 5.8, min = 4.3, max = 6.8). The perceived control as well as the perceived safety were rated as moderate to good (perceived control: Md = 6.0, min = 2.0, max = 10.0; perceived safety: Md = 6.5, min = 2.0, max = 10.0). The workload for the remote operator HMI was rated as moderate (Md = 10.5, min = 2.3, max = 20.0), which was notably higher than the workload for the dispatcher HMI. The overall usability as well as all three scales are rated as rather moderate (total: Md = 4.7, min = 3.2, max = 7.0; information quality: Md = 4.4, min = 2.4, max = 7.0; interface quality: Md = 4.8, min = 3.0, max = 7.0; system quality: Md = 5.1, min = 3.3, max = 7.0). The level of immersiveness of the remote operator HMI was rated inconsistently, with participants noting challenges, particularly in the classification of the lateral distances (Md = 3.0, min = 1.0, max = 9.0), reactivity of the system (Md = 5.0, min = 2.0, max = 9.0), and interaction with the environment (Md = 5.0, min = 3.0, max = 9.0).

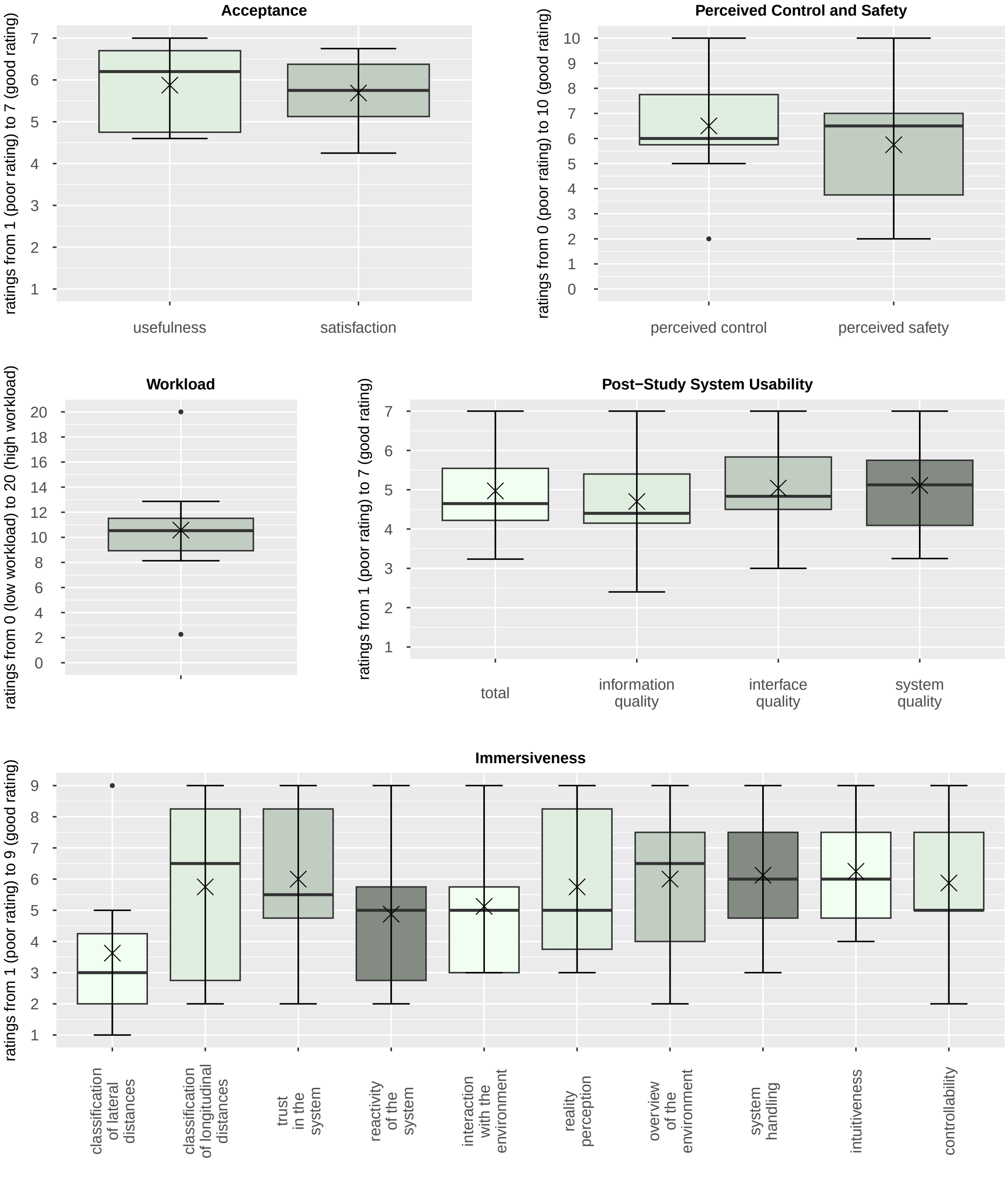

Figure 4: Results for acceptance, perceived control and safety, workload, usability and immersiveness for the remote operator HMI (n=8).

The analysis of the interview data also reveals a number of potential avenues for optimization with regard to the remote operator's HMI. These relate, in particular, to enhancements in control support and the design and presentation of relevant information.

A primary recommendation from the participants was the design of camera views that would reflect the perspective of a conventional driver as realistically as possible. It is recommended that the central view to the front be displayed in a larger size than the views from the side and rear-view mirrors, and that visual distortions be avoided at all costs. In order to more accurately assess the dimensions of the vehicle, it is recommended that the exterior bodywork be visible at the periphery of the image. The controllability of the front camera, in particular through functions such as rotating and zooming, could facilitate object recognition and thus enhance control.

Furthermore, the integration of a bird's eye view of the vehicle, analogous to the parking assistants found in conventional vehicles, has been proposed. This view could assist in more accurately assessing the surrounding environment. Additionally, the incorporation of visual aids, such as color-coded safety corridors, has been proposed to facilitate distance estimation. The incorporation of a scale at the periphery of the field of view or in the form of augmented reality between the obstacle and the vehicle would also prove advantageous. Moreover, the provision of acoustic feedback, analogous to that provided by a parking assistant, could serve to clarify the distances to obstacles. Furthermore, the display of an ideal line with steering angle and speed was identified as a beneficial addition, as it would facilitate steering. Similarly, the transmission of ambient noise in a more discernible manner was regarded as advantageous, as it would assist in localizing approaching vehicles or people.

In order to facilitate a more comprehensive overview, it was advised that the overview map from the dispatcher's HMI be integrated on a distinct monitor. The map could serve as a comprehensive representation of the operational area, thereby assisting the remote operator in navigating it. Furthermore, pertinent traffic regulations, such as speed limits or overtaking prohibitions, should be displayed in real time.

It is further recommended that the visual feedback indicating whether the driver is currently in control of the vehicle be emphasized with greater clarity. This objective could be accomplished by implementing a wider turquoise border around the screen or incorporating additional light strips into the workstation design.

4 Discussion and Conclusion

The findings of this study confirm the general efficacy of the dispatcher HMI in the management of automated vehicle fleets. The positive acceptance and usability ratings, in conjunction with the low workload, indicate that the HMI is aligned with user needs. The high appreciation expressed for the features, such as the overview map and the color-coded vehicle status, aligns with previous findings that have emphasized the importance of intuitive and informative visual displays in operation centers [10, 11]. However, there are areas that require further development, such as improved error message handling and enhanced video feeds.

The moderate ratings for usability and immersiveness, along with the high workload, indicate that there are significant areas for improvement in the remote operator HMI. Participants demonstrated particular difficulty with spatial awareness and control, underscoring the necessity for augmented reality features such as safety corridors, vehicle trajectory visualization, and enhanced camera perspectives. These findings support the recommendations of earlier research [3, 5, 6, 18], which emphasized the importance of

AR-enhanced visual aids and realistic camera views to support remote operation.

However, the study is limited by its small sample size and the technical issues affecting the remote operator tasks, which restricted the robustness of the findings. It would be beneficial for future work to focus on implementing these recommendations, reassessing the HMIs with larger samples in realistic settings, and exploring scalable solutions for managing larger vehicle fleets and designing dispatcher and remote operator communication. Furthermore, it is essential to assess the technological requirements of the automated vehicle and to what extent the implementation of these requirements is feasible.

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