US DOT National
University Transportation Center for Safety

Real-world observations and human factors evaluation of AV shuttle operations

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Final Report – July 31, 2025

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Technical Report Documentation Page

<table>
<tr><td>1. Report No.
563</td><td>2. Government Accession No.</td><td>3. Recipient’s Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Real-world observations and human factors evaluation of AV shuttle operations</td><td>5. Report Date
July 31, 2025</td></tr>
<tr><td>6. Performing Organization Code
N/A</td></tr>
<tr><td colspan="2">7. Author(s)
Sarah Fox, PhD https://orcid.org/0000-0002-7888-2598
Nikolas Martelaro, PhD https://orcid.org/0000-0002-1824-0243</td><td>8. Performing Organization Report No.
N/A</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213</td><td>10. Work Unit No.
N/A</td></tr>
<tr><td>11. Contract or Grant No.
Federal Grant # 69A3552344811 / 69A3552348316</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
Safety21 University Transportation Center
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213</td><td>13. Type of Report and Period Covered
Final Report (July 1, 2024 – June 30, 2025)</td></tr>
<tr><td>14. Sponsoring Agency Code
USDOT</td></tr>
</table>

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

Enter information not included elsewhere, such as translation of (or by), report supersedes, old edition number, alternate title (e.g. project name), hypertext links to documents or related information in the form of URLs, PURLs (preferred over URLs - https://archive.org/services/purl/help), DOIs (https://www.doi.org/), insertion of QR codes, copyright or disclaimer statements, etc. Edit boilerplate FHWA statement above if needed.

16. Abstract

The integration of autonomous vehicle (AV) shuttles and advanced driver assistance systems (ADAS) into public transit is positioned as a means of enhancing safety, accessibility, and operational efficiency. However, these technologies also transform the role of human operators, who must intervene during complex and high-risk scenarios. This study examined human factors in AV shuttle operations and ADAS testing through ethnographic observations, interviews, and human factors evaluations in both live service and controlled testing environments across the U.S. and Canada. Findings reveal that ergonomic strain, sustained cognitive workload, unclear communication protocols, and insufficiently realistic testing conditions can diminish the intended safety benefits of automation. AV shuttle attendants faced physical discomfort from poorly designed seating and display placement, while remote monitoring staff contended with fragmented alert systems and inconsistent communication pathways. ADAS collision avoidance testing often failed to reflect real-world operating conditions, limiting the relevance of results. Recommendations include ergonomic workstation redesign, improved alerting and communication systems, operator-centered training, and scenario-based testing that mirrors operational complexity and diversity. Embedding operator perspectives in design, testing, and deployment processes can ensure that automation effectively supports safe and efficient transit operations.

17. Key Words	**18. Distribution Statement**
Public Transit; Advanced Driver Assistance Systems; Autonomous Vehicle Systems; Buses; Workforce; Labor Relations	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161. Enter any other agency mandated distribution statements. Remove NTIS statement if it does not apply.

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
N/A	N/A	1-9	N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Executive Summary

Autonomous vehicle (AV) shuttle deployments and advanced driver assistance systems (ADAS) are emerging as critical tools to enhance the safety, accessibility, and operational efficiency of public transit. These technologies, however, also redefine the role of human operators, both onboard and in remote monitoring centers. This study undertook a detailed examination of the human factors associated with AV shuttle operations and ADAS in real-world transit contexts.

Fieldwork was conducted with an AV shuttle service provider operating in multiple U.S. cities and with a public transit agency in Canada during controlled testing of an ADAS collision avoidance system. In both contexts, the research team observed live operations, conducted interviews with operators and support staff, and performed human factors evaluations. The results indicate that ergonomic strain, high cognitive workload, communication gaps, and unrealistic testing scenarios can undermine the safety benefits of these technologies. The findings led to recommendations for redesigning workstations, improving operator training, enhancing communication protocols, and creating more realistic and inclusive technology testing practices.

Problem Statement

Automation in transit is often positioned as a means to reduce human error, improve operational efficiency, and expand accessibility. However, when automation shifts routine tasks away from human operators, those operators are left to intervene primarily during rare, complex, and high-stakes situations. These moments require not only quick reactions but also a deep understanding of the system's capabilities and limitations.

Evidence from previous AV shuttle incidents illustrates that when human-machine interaction is poorly designed, operator intervention can be delayed or ineffective. Skill atrophy, mode confusion, and inadequate situational awareness can all emerge when operators are disengaged for extended periods. In transit environments—where vehicles operate in close proximity to pedestrians, cyclists, and mobility device users—any reduction in operator effectiveness can have significant safety consequences.

Furthermore, ADAS technologies intended to assist operators must be tested under realistic operational conditions. Evaluations that occur only in controlled environments with simplified hazards may fail to reveal critical limitations in system detection or operator response. This project aimed to identify these limitations and propose interventions that align automation more closely with the demands of real-world transit operations.

Research Approach and Methodology

The research was conducted in two phases. In the first phase, the team undertook ethnographic observations and interviews in multiple U.S. cities where an AV shuttle service provider operates autonomous and electric vehicle shuttles. Observations were conducted both onboard shuttles and in the provider's remote operations center, where staff monitor fleet activity and provide assistance when necessary. Operators, attendants, and support staff were interviewed to gain insight into their daily tasks, ergonomic challenges, cognitive demands, and experiences interacting with passengers and technology.

During this same phase, the research team traveled to a Canadian city to observe testing of a collision avoidance warning system on transit buses. The testing was conducted at a specialized facility and involved simulated pedestrian encounters, controlled turns, and varied approach speeds. Interviews were conducted with bus operators, joint health and safety representatives, engineers, and vendor staff to assess the realism of the testing scenarios, the clarity of system alerts, and the operators' comfort with the technology.

The second phase of research focused on human factors evaluation. For the AV shuttle operations, physical and cognitive task analyses were conducted, along with ergonomic assessments and process mapping. For the ADAS testing, the evaluation examined the visibility and timing of alerts, the interaction between operators and the alert system, and the degree to which the scenarios reflected real-world hazards. Data sources included observation notes, interview transcripts, system log data, location tracking, video and eye-tracking recordings, and operator feedback sessions.

Findings

In the AV shuttle operations, onboard attendants experienced significant ergonomic strain. The seating lacked adequate lumbar support and cushioning, and the cabin layout required frequent pivoting to monitor surroundings, contributing to physical discomfort. In one deployment site, complex traffic environments and frequent manual interventions led to sustained cognitive workload, with attendants describing the work as both mentally and physically fatiguing. The in-shuttle display was positioned at an awkward height, causing attendants to raise their arms frequently to interact with it, which reduced accuracy and increased strain over time.

Remote monitoring staff in the operations center managed multiple shuttles through a combination of software platforms, often requiring more than ten windows to be open simultaneously. Critical alerts were presented only as visual cues within a single application tab, increasing the risk of oversight during high workload periods. No audible alerts were available for urgent issues, limiting the operators' ability to maintain awareness while multitasking. Communication protocols were inconsistent; for example, the onboard emergency call button routed to an overseas support center rather than to the local monitoring team. Additionally, diagnostic data from shuttles were not always available remotely, leading to improvised solutions such as sending photographs via messaging platforms for troubleshooting.

The ADAS testing revealed limitations in both technology performance and evaluation design. The collision avoidance system did not consistently provide timely or effective alerts for scenarios such as left turns, higher-speed approaches, detection of shorter pedestrians or mobility aid users, or pedestrians outside the direct path of the vehicle. Operators often did not see visual alerts due to panel placement and instead relied on the audible warning, which triggered later in the hazard sequence.

Operators noted that the testing scenarios were often unrealistic. Speed was limited to 20 km/h, much lower than typical service speeds, affecting operators' judgment of distance and timing. Scenarios involved only a single pedestrian and did not reflect the complex environments of real routes, which often include multiple moving hazards. Side-sensor performance was rarely tested, and the pedestrian dummies lacked variation in body size, skin tone, and mobility aids beyond a narrow set of examples.

Operators in both contexts valued being included in early stages of technology evaluation but stressed the need for stronger feedback mechanisms. In some cases, their instinctive responses to hazards, such as braking early, conflicted with instructions intended to test reaction time, revealing the difficulty of reconciling simulated testing conditions with real-world practices.

Conclusion and Recommendations

This research affirms that human factors are a critical determinant of success in the deployment of AV shuttles and ADAS in transit. Operators serve as an essential safety layer, but their effectiveness can be compromised by poorly designed interfaces, high cognitive workload, unclear communication channels, and inadequate training. Testing conditions that fail to replicate real-world complexity may overlook system limitations, while insufficient engagement with operators during design and evaluation risks producing technologies that are misaligned with operational realities. Embedding operator perspectives into every stage of development—from scenario design to interface layout to training—can help ensure that automation supports, rather than hinders, safe and effective transit operations.

Future AV shuttle deployments should include ergonomically designed seating and controls for onboard attendants, as well as repositioned displays that reduce physical strain and allow operators to monitor both passengers and roadway conditions without frequent head or body rotation. Remote operations centers should introduce audible alerts for urgent conditions, provide larger or additional monitors for better situational awareness, and establish clear monitoring responsibilities for each operator.

For ADAS evaluation, testing should replicate real-world conditions as closely as possible, including realistic speeds, complex and dynamic pedestrian scenarios, varied environmental conditions, and a diversity of pedestrian profiles. Alert systems should be designed to ensure that both visual and auditory cues are noticeable without obstructing the operator's view of the road.

Training should be developed for both operators and maintenance personnel, covering not only how the technology functions but also its limitations, maintenance requirements, and performance under varying environmental conditions. Pilot deployments should be strategically planned to include a range of routes, operating conditions, and operator demographics to ensure findings are broadly applicable. Continuous feedback channels should be maintained throughout deployment to allow operator input to inform iterative improvements in system design and operation.

Project Outputs and Outcomes

The project resulted in two human factors evaluation reports, one focusing on onboard operations and the other on remote monitoring. A series of process, training, and interface design proposals were developed and shared with the AV shuttle service provider. Two academic papers were published in peer-reviewed venues in human-computer interaction and transportation research, with an additional submission planned. A white paper is being developed to translate these findings into actionable recommendations for industry. In addition, specific recommendations were delivered to the Canadian transit agency to guide the design and evaluation of their collision avoidance system pilot.

Final Report URL(s) or PDFs for any resulting publications:

Project site: https://codesigningtransit.com/

Hunter Akridge, Alice Xiaodi Tang, Nikolas Martelaro, and Sarah E. Fox. 2025. Punctuated and Prolonged: A Workers' Inquiry into Infrastructural Failures in Bus Transit. Proc. ACM Hum.-Comput. Interact. 9, 2, Article CSCW016 (May 2025), 25 pages. https://doi.org/10.1145/3710914

Alice Xiaodi Tang, Hunter Akridge, Nikolas Martelaro, and Sarah E Fox. 2025. At the Breaking Point: How Bus Operators Cope with Transit Technology Failures and What That Can Tell Us About the Integration of Future Innovations. In Proceedings of the 2025 ACM Designing Interactive Systems Conference (DIS '25). Association for Computing Machinery, New York, NY, USA, 3621–3634. https://doi.org/10.1145/3715336.3735728

Hunter Akridge, Sarah E. Fox, Alice Xiaodi Tang, and Nikolas Martelaro. 2025. “Health and Safety Sidelined: The Need for Effective and Non-Punitive Reporting Mechanisms in Transit Work.” Safety21. https://safety21.cmu.edu/2025/04/25/new-policy-brief-health-and-safety-sidelined-the-need-for-effective-and-non-punitive-reporting-mechanisms-in-transit-work/

URL(s) to, and associated descriptive metadata for, any final datasets from the research project

N/A

Any documented project outputs or outcomes resulting from the research project.

Presentation at SXSW 2025 in Austin, TX

Presentation at the Informatics Colloquium Series, Indiana University

Presentation at Human-Computer Interaction Seminar, Stanford University

Presentation at Amalgamated Transit Union Legislative Conference in Washington, DC

Presentation at National Transit Workforce Conference in Baltimore, MD

Presentation at New York City Central Labor Council/New York Committee for Occupational Safety & Health (Virtual)

Presentation at ACM Designing Interactive Systems Conference in Madeira, Portugal