How to Make Sense of Bus Transit Automation?

Considerations for policy makers on the future of human-automation teaming in the transit workforce

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Executive Summary

Automated vehicle technology has the potential to fundamentally impact public transit operations. While private companies have ambitious plans for automated vehicle deployment, operating transit is more complex than light-duty passenger vehicles. Buses, for example, are significantly larger and operate in highly variable environments near vulnerable road users. Even in the case of smaller vehicles such as vans, there are still many technical challenges to overcome to navigate these complex environments safely. Furthermore, transit operations require supporting passengers and maintaining safety inside the vehicle. Due to both technical and operational challenges, transit vehicles including buses and vans will be highly likely to continue to require skilled human operators, even as automated vehicle capabilities are incorporated. The introduction of new technology will impact operator's duties and actions, as well as passenger safety and experience. Consideration of new federal policies will be important for the future of work for the 162,850 transit operators currently employed in the United States. To help maintain transit's high level of safety for passengers, it will be important to understand how automation stands to affect the roles and day-to-day tasks of trained operators. Driver assistance automation such as pedestrian warnings and lane-centering has the potential to improve the safety and workload of trained operators. At the same time, automation can create new kinds of safety issues caused by the interactions in human-autonomy teams, and can intensify work as people primarily take over from automation in the most challenging situations. It is crucial that public transit authorities preemptively consider the safety of incorporating automation technologies into their fleets, and train operators to work effectively with such technologies. Furthermore, it will be important to collect data on automated systems via improvements in communications and data sharing infrastructure so that regulations and safety requirements can be grounded on data. The following document describes these considerations in further detail and makes the following recommendations for policy makers to consider around automation in transit operations.

Recommendations:

1. The US Department of Transportation (US DOT) should research the added work tasks and potential new stresses placed on transit bus and van operators as autonomy prompts transitions from physical operation to supervision and emergency takeover control.

2. The Federal Motor Carrier Safety Administration (FMCSA) and the Federal Transit Administration (FTA) should support research on active and passive systems that can improve a transit operator's ability to maintain safety on the road. Regulation, legislation, and guidance on such technology should be updated as new technologies are proven safer.

3. The US DOT along with the FTA Bus Testing Program should develop new oversight measures and requirements to ensure safety isn't degraded as transit systems might consider autonomous buses and vans that are marketed as capable of operating without a human operator on-board.

4. The US DOT and FTA should support a hazard analysis of Level 3-5 automation in transit operations and should support local authorities in conducting their own hazard analyses as part of their Public Transportation Agency Safety Plan. These analyses should include frontline employees and their unions.

5. The US DOT and its modal agencies should invest in infrastructure innovations to support data collection, sharing among agencies, and oversight of automated transit operations.

State of Vehicle Automation

The 2007 US Department of Defense DARPA Urban Grand Challenge demonstrated that highly automated, driverless vehicles were technically feasible to accomplish typical urban driving actions. Since then, a variety of private companies throughout the world have taken the lead in developing automated technology for vehicles. In 2013 companies began on road demonstrations, showcasing technological advancements in the area, as well as intensive investment. Cutting through this hype, in 2018, a highly automated vehicle using a system developed by Uber Technologies struck and killed a pedestrian walking a bicycle across a street in Tempe, Arizona (NTSB 2018). Exposing the continued vulnerabilities of automated vehicle systems, the vehicle's sensors detected the pedestrian, but did not identify the obstacle as a pedestrian until seconds before the crash (Figure 1). Factory installed emergency braking was disabled for the automation software, and the driver was not actively engaged in controlling the vehicle until a second before the collision.

While private companies continue to have ambitious plans for automated vehicle deployment, it has become apparent that driverless capability under all driving conditions is very challenging. However, there needs to be accountability with the introduction of autonomous driving systems, as the current industry approach of enrolling the general public as beta testers and treating open roadways as pilot sites can have deadly consequences. This is particularly salient when driver expectations on the performance of the autonomous system do not match their current capabilities, such as a 2021 Tesla crash where the car ran into a tree while the occupants were in the passenger and backseat with no one behind the wheel (Wong 2021). Vehicles with partial automation, requiring a human driver to resume control when needed, will likely be common for some time. In transit, fully automated road vehicles may be deployed in niche services such as low speed ride hail or shuttle services in controlled environments, on dedicated rights-of-way, and low-density roadways, but given the current state of vehicle automation and the heightened complexity of driving near many pedestrians and in various environmental conditions, trained human operators will likely be needed as increasing levels of automation are introduced to transit busses and vans.

Levels of Vehicle Automation

The Society for Automotive Engineers (SAE) outlines a set of standards for six levels of vehicle automation. In contrast to highly automated driving features (SAE levels 3-5), SAE levels 1 and 2 partial automation/driver support features are commercially available and becoming common in new vehicles offered for sale, including transit vehicles. These partial automation features can

Figure 1: 2018 fatal crash of a highly automated vehicle deployed by Uber in Arizona. Left: Path of pedestrian (orange) and vehicle (green). Right: post-crash view of vehicle. Source (NTSB 2019).

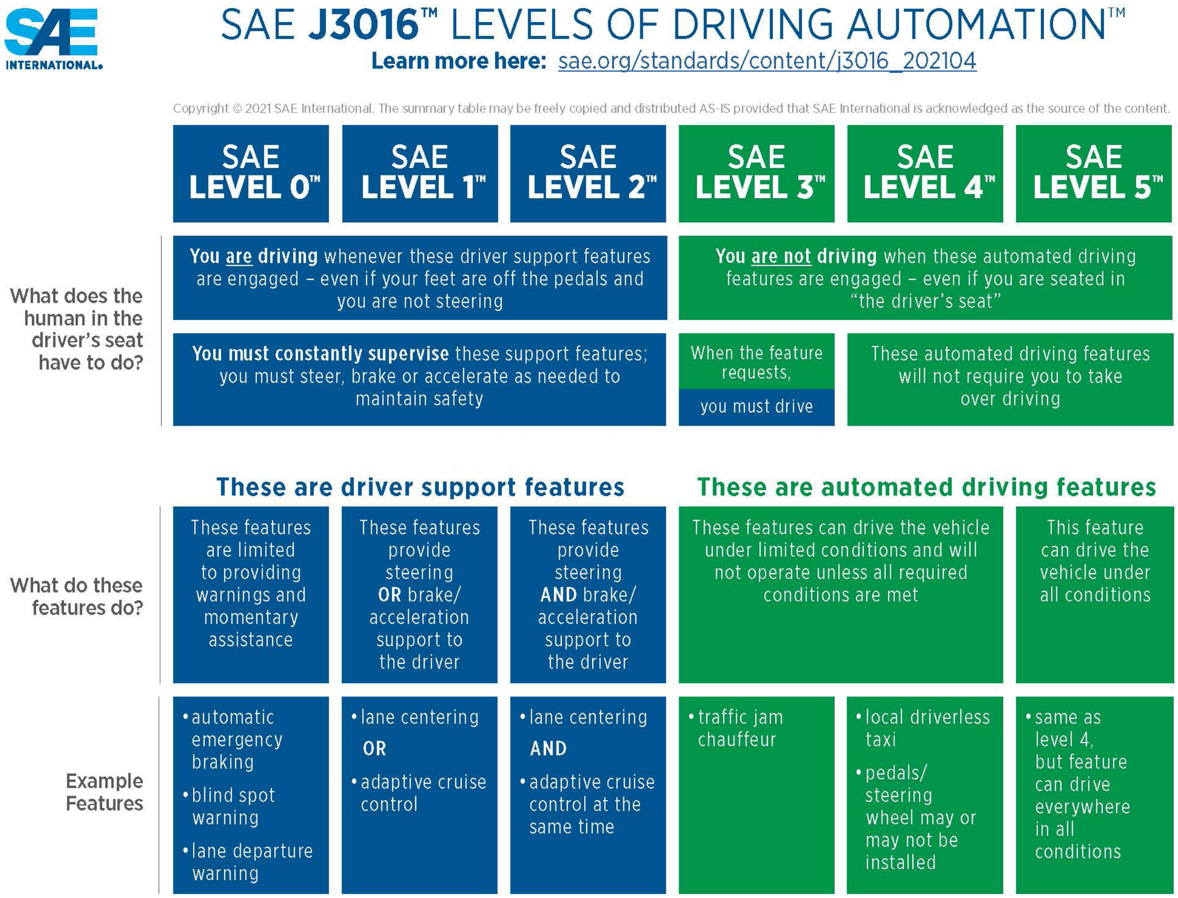


Figure 2: SAE Levels of Driving Automation (Source: https://www.sae.org/standards/content/j3016_202104/)

improve vehicle safety and reduce the burden of driving. Partial automation for electronic vehicle stability and automatic emergency braking, for example, are becoming standard and features such as adaptive cruise control and driver warning systems have found considerable consumer acceptance. Beginning in 2022, Germany authorized Mercedes to sell its Drive Pilot in limited conditions, representing the first commercial application of SAE Level 3 conditional automation (MacKenzie 2022). Under Level 3, a driver is required to be in the vehicle but does not have to continually monitor the driving function, as in Levels 1 and 2. Still, the driver must be ready to take over control of the vehicle upon system request. Other companies, such as Honda, are developing similar Level 3 automated systems and are expected to appear on the market soon (Beresford 2021).

Automated Commercial Vehicles

Beyond individually owned vehicles, various highly automated commercial vehicle business models are currently being tested. In some circumstances, these vehicles are truly driverless with no person operating during pilot deployments on public roadways. Common business models include:

- Driverless Robo-Taxis from GM Cruise (Ohnsman 2021) and Waymo (2022) are operating automated shared ride passenger vans and SUVs commercially in San Francisco.
- Automated "pods" from companies such as EZ Mile and Navya allow slow speed transport of up to 12 passengers in relatively contained roadways such as the Las Vegas Strip (Hawkins 2017) or on college campuses.
- Driverless Trucks from Tu Simple and Gatik (partnered with Walmart) have automated trucks on roadways in limited conditions with no safety driver on board (Holland 2021).

Such operations are increasingly moving toward deployment without human drivers. For example, in December 2021, France approved the EZ Mile 12-person pods to operate without a driver on-board (Bateman 2021). Another developing business strategy is to employ remote human supervision as backup for on-board automated systems. Phantom Auto, Starsky Robotics, and Waymo have all developed systems for automated vehicle remote control (Lekach 2019). **Remote supervision demonstrates the convergence of automated vehicle technology, connected vehicle technology, and human oversight — with all three playing a critical role in automated vehicle operations.**

Current Applications of Vehicle Automation in Transit

Vehicle automation has been applied to transit operating in “closed” systems such as a rail bed or fixed track for rubber tire people movers for many years. Beginning in 1967 in London, these are defined as a Grade of Automation (GoA) Level 4 requiring no driver and are popular today in limited areas (e.g., airport “people movers”). Although automation is common in rail, there is a significant jump in the level of complexity and risk when moving from closed to open road systems. Such complexities include interactions with varied infrastructure, other vehicles, and vulnerable road uses. Though we acknowledge the longer history of fixed rail transit automation, this policy brief will focus on newer technology and applications of bus transit automation.

Beginning in 2015, Navya and EZ Mile commercialized six-passenger electric shuttles operating at 15.5 mph without steering wheels or pedals (Navya n.d.). Currently, these vehicles have on-board attendants who are able to take control of the vehicle with a joystick in the case of an emergency. These vehicles operate on roadways with regular traffic, and comprise the majority of current foreign and domestic AV transit pilot projects. Below are various types of vehicle automation in transit.

- Positive Train Control in Commuter Rail is a complex signaling and communications technology that provides redundant safety features in commuter rail services. As of December 31, 2020, the American Public Transportation Association (APTA) reported that every commuter railroad was required to be certified by the Federal Railroad Administration (Federal Rail Administration 2021).

- Grade of Automation (GoA) Level 4 Driverless light rail vehicles have been deployed in cities such as Busan, Korea and the Pittsburgh International Airport.

- Driverless Slow Speed Shuttles (6-12 passenger capacity) have been operating on roadways since 2015 without traditional steering wheels and pedals, but with safety attendants who are able to control the vehicle with a joystick in the case of emergency. Companies utilizing these systems include Local Motors, Navya and EZ Mile.

- Automated vans, such as Waymo vehicles in Arizona, are providing last mile and on demand services for transit agencies.

- Hamden, Connecticut and other US cities are actively preparing to deploy full-size (40-ft), highly automated electric buses with steering, precision docking, and platooning capabilities (Connecticut Department of Transportation 2020).

- Bus platooning involves several buses driving close together in a line — sharing distance, speed, and braking information — is being explored by the Port Authority of New York and New Jersey (Higgs 2019).

- SAE Level 1 and 2 partial automated systems such as forward collision warning, blind spot detection, lane keeping, pedestrian detection, automatic emergency braking are being adopted in numerous fleets across the country.

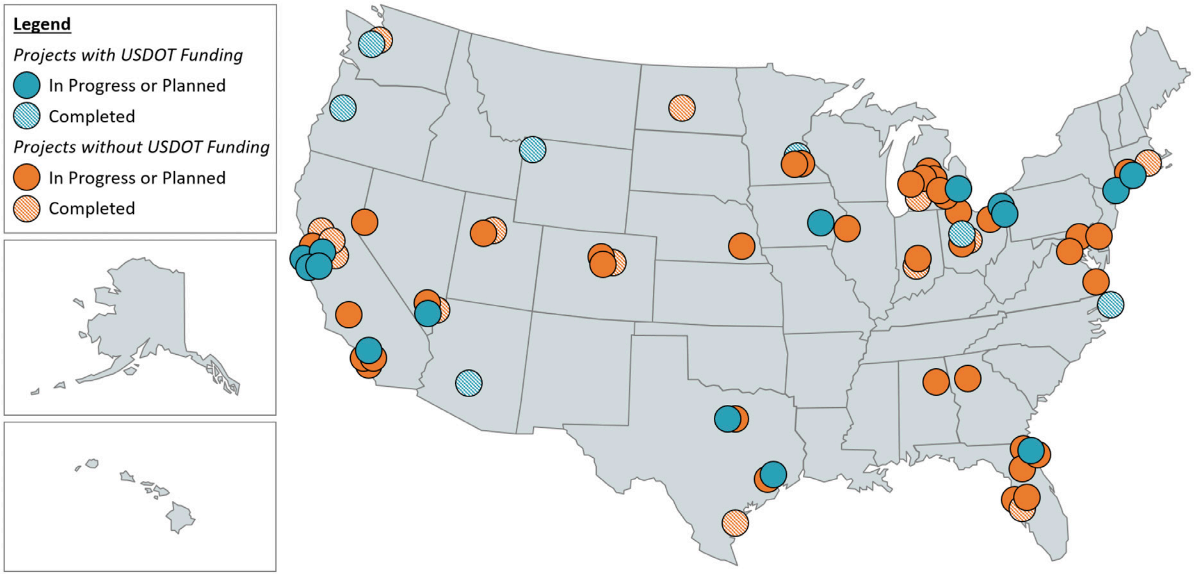


Figure 2: Completed, Current and Planned Automated Transit Pilots within the US (Source: Transit Bus Automation Quarterly Update Q3 2021, Federal Transit Administration)

Many transit agencies have received USDOT funding for automated vehicle test activities. Some of this funding has been provided through Federal Transit Administration (FTA) programs, such as:

- Accelerating Innovative Mobility (AIM)
- Congestion Mitigation and Air Quality (CMAQ) Improvement Program
- Innovative Safety, Resiliency, and All-Hazards Emergency Response and Recovery (SRER) Research Demonstrations
- Integrated Mobility Innovation (IMI) Demonstration Program
- Mobility on Demand (MOD) Sandbox Program
- Safety Research and Demonstration (SRD) Program
- Strategic Transit Automation Research (STAR)
- Vehicle Assist and Automation (VAA) Demonstration

Additional projects have been funded by other USDOT modal administrations or by departmental programs:

- Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program
- Automated Driving System (ADS) Demonstration Grants
- Better Utilizing Investments to Leverage Development (BUILD) Program
- Federal Highway Administration (FHWA) Office of Federal Lands Highway (FLH)
- Federal Lands Transportation Program (FLTP)
- FHWA Technology and Innovation Deployment Program (TIDP)
- Smart City Challenge (SCC)

Overall, there is significant investment in piloting new automated vehicle technologies within transit. These pilots will help provide data on the applicability and technology readiness of automated vehicle features in transit applications. Given these investments and new automation, the impact on employment opportunities within transportation should be considered. **Automation has the potential to both alleviate certain challenges with current driving tasks, but may also introduce new challenges and work intensification.** Further, automation could eliminate jobs, but the complexity of autonomous vehicle services may also create new jobs for supervising and managing on-road autonomous systems and for maintaining highly-complex and computerized vehicles. This transition may be disruptive though for workers who do not receive the needed training to work with such highly automated systems. Today, there are still many technical challenges to overcome on the way towards autonomy. **The question of necessary human involvement in light of these shifts towards automation in transit remains.**

Technical Challenges of Highly Automated, Driverless Vehicles

Media and popular attention on automated vehicles has largely focused on the prospect of widespread deployment of highly automated, driverless vehicles. Yet, commercial challenges to making driverless vehicles robust and reliable under varied conditions and in mixed traffic require advances in computing and sensing technologies.

SENSOR TYPE	FUNCTION	CHALLENGES
LIDAR (light detection and ranging)	Measures distances, helps software build 3D map, more detailed detection of obstacles	Limited functionality in precipitation: rain, snow, etc.
Radar	Measures distance to obstacles. Sensors are mounted on the front, rear, and side	Limited aperture/field of view
Cameras	Used for lane demarcation, obstacle detection, traffic sign identification; mounted for 360-degree views.	Can be blinded in certain conditions / limited functionality depending on light conditions
Environmental sensors	Identify temperature and precipitation conditions	Prone to failure due to wear and tear, weather conditions
Global Navigation Satellite Service (GNSS) and stored maps	Stored roadway maps with detail on lane geometry and operational rules such as stop signs	Updates and connectivity are needed regularly to insure accuracy

Multiple levels of software are required for perception, planning, and control. At the perception level, sensor data must be integrated with map information and a model of the vehicle surroundings created including identification of obstacles. Planning for vehicle actions involves both strategic decisions about routes as well as tactical issues of lane choice. Control of vehicle actions converts plans into specific outputs for vehicle functions such as throttle or turning. In addition, in-vehicle sensors provide data on vehicle performance and situation, such as speed and direction. All of these sensors provide a huge amount of data on the vehicle and its surroundings.

A primary area of concern for highly automated vehicles is their ability to identify and avoid vulnerable road users in varying conditions. A second area of concern for highly automated vehicles is their ability to maneuver in mixed traffic. For example, drivers and cyclists occasionally use hand signals to communicate with other drivers. Similarly, police use hand signals to direct traffic when needed. Identifying and interpreting such hand gestures is a major challenge. Eye contact between drivers is often used to determine if it is safe to proceed through an uncontrolled intersection; there is no parallel mechanism to communicate between autonomous vehicles and the rest of the world.

Automated Vehicles Challenges

Exogenous: The complexities and uncertianties of the real world.
Weather, lightning, and road conditions; construction; accidents; obsolete information, loss of GPS.

Endogenous: Online and safe recovery from failures of sensors, actuators, computing or communications.
Mis-calibration, wear and tear, failures.

Verification: How to verify and validate correctness?

Interactions: Vehicular Networks

Reliability: cost and maintenance, customer acceptance

Cyber-Physical Security: thwart connectivity portal attacts

Human factors

Incremental deployment

Legal and regulatory implications

More work to be done*
** Larger questions marks denote more uncertainty*

Significant progress made

Figure 3: Automated vehicle development challenges are outlined above. Progress in addressing these challenges since 2007 has been uneven along different fronts.

Several operational challenges exist for highly automated vehicles, including:

- How can driverless vehicles become highly reliable in varying conditions?
- What programs are needed to train maintenance staff on new automated vehicle technologies?
- What are the new job functions of transit vehicle operators in partially and highly automated vehicles, and what skills and training are necessary?
- What programs are needed to aid drivers whose roles have been dis- or replaced?
- How will costs of procuring new automated vehicle technology impact municipal budgets?

As automated vehicle technology is introduced in transit operations, trained operators will continue to play a critical role. The introduction of new technology will impact their duties and actions, as well as passenger safety and experience. Consideration of new policies will be important for the future of work for the 162,850 transit operators currently employed in the United States (U.S. Bureau of Labor Statistics 2020).


navya

Additional Burdens on Transit Operators

Given that many automated vehicle technologies may support rather than replace drivers, it is important to consider the impact of these technologies on transit operators' work. The transition towards automation in the airline industry provides historical precedent on the impacts of automation on human work. While commercial aircraft have been equipped with automated controls for many years, there is still a need for trained pilots in the cockpit due to a number of challenges that arise when automation is introduced. Over time, pilot workload has shifted away from physical demands towards increased cognitive demands (Dekker and Woods 1999) where flying becomes more supervisory. In many ways, automation has elevated the role of pilots as they become more skilled in the operations of flight control systems (Kantowitz and Campbell 1996; Roy 2017) and in their ability to take over in challenging situations. For example, Captain Chelsey Sullenberger 2009 Hudson River landing highlights how a skilled pilot stepping in can quickly save lives during an emergency situation not handled by autopilot features (Sullenberger 2015).

One of the classic problems with automated systems is "automation surprise," where operator expectations about an automated system are violated, leading to conflicts (Palmer 1995). Another is mode error, where operators do not know what mode of automation they are in (Sarter and Woods 1995). Dehais et al. (2015) spoke to the need for design solutions that detect these conflict situations. A related crucial component in the design of automated safety critical systems is the handoff of authority from system to human, or "authority sharing" (Boy 2009). Studies on the transfer of control to automated systems point to a negative perception of one's ability and loss of control. In autonomous driving, operator convenience is traded for control (Rödel et al. 2014), but safety concerns outweigh those benefits. Further explorations of the design for "human in the loop" addresses other automation conflicts for other human-AI systems (Cummings and Bruni 2009). This approach to design will become more important if, as we suspect, there are definitive conclusions reached about the need for human operators on-board in the complex operating environment of passenger transit systems.

Although it seems counter-intuitive, increased automation can actually make the task of operating a vehicle more challenging. As automation takes over more routine aspects of driving, operators are left to manage the most challenging situations. Research on this phenomenon shows that reaction time increases as time disengaged from the task of driving increases, regardless of cognitive engagement (Funkhouser and Drews 2016). Within aviation, automation has reduced many common crash scenarios; however, it has also created new, more complex situations leading to new kinds of crashes (Casner and Hutchins 2019) as evidenced by the tragic Boeing 737 MAX MCAS crashes.

We are already seeing these "new crashes" in automated transit. In 2017 an autonomous Navya shuttle in Las Vegas was hit at low speed by a truck backing up (NTSB 2019). In this incident the attendant, who had 3-years experience driving 40ft buses and received training from Navya, hit the emergency button when the vehicle stopped successfully for the truck, but did not have time to switch the vehicle to manual mode and avoid the collision. The operator and the operation company, Keolis, stated that "the manual mode was not designed or intended to be used as an emergency mode" (NSTB 2019, pg. 12) suggesting that there was limited design consideration for emergency situations where an operator could intervene. Another incident includes when a blind paralympian was struck by an autonomous shuttle at the Tokyo Olympics — a incident later determined to be caused by the operator overriding the autonomous system, wrongly assuming that the pedestrian could see and would not cross the road as the shuttle passed. While one may jump to say that the incident was caused by human error, it is more appropriate to consider this **a failure of human-automation teaming and a lack of understanding around the complexities that automation brings even to simple, low-speed situations**.

As a further complication, while automation will likely bring about new and more complex incident situations, **a lack of proper training and a shift to operators supervising rather than driving can lead to the degradation of a worker's driving skills when they are needed, also known as skill atrophy** (Pettigrew, Fritschi, and Norman 2018). Within aviation, prior research has found that pilot skills can decrease over time with the increased use of automation, again being even more of an issue as the moments when pilot intervention is needed become more challenging (Ebbatson et al. 2010). For example, pilots can have problems performing complex cognitive tasks needed if automation degrades on the flight deck, often associated with how much

Level of Automation	*Pro*	*Con*
0 - No Automation	Current status quo, no new training required	Missed opportunities for safety improvements and driver quality of life improvements
1 - Driver Assistance	Improved safety and quality of life for drivers, similar to features in passenger vehicles	Misinterpretations of system capabilities
2 - Partial Automation	Improved workload reduction for things such as cruising and lane centering	Limited use in complex urban environments
3 - Conditional Automation	Increased physical workload reduction for drivers	Increased cognitive load from vehicle monitoring New crashes caused by autonomy-operator interaction
4 - High Automation	Drivers reduce much of their active driving time and efficiency and safety may increase	Operator skill atrophy Driver intervenes during hard situations requiring more readiness (e.g., training, practice).

pilots are engaged in thoughts unrelated to the task of flying (Casner et al. 2014). In effect, pilots who are not engaged in the task of flying due to automation can have reduced abilities to engage when needed during the most challenging of situations.

In ground transportation, automation issues may become magnified due to a number of factors. First, road vehicles operate in highly complex spaces with many vulnerable road users. Response times to avoid incidents on the road are on the order of seconds (rather than minutes while flying). Second, transit operators must manage a number of other tasks beyond driving, including stressful interactions with the public, constant interruptions, and road or weather emergencies (Cunha et al. 2021). Third, changes in human-machine interfaces such as replacing steering wheels for joysticks could impact the ability for an operator to safely control a vehicle in a high stress situation. Given the skills drivers have today, it is still unclear how interfaces that deviate from traditional controls (wheels and pedals) would work for road vehicles, especially under emergency situations. Future changes to vehicle interfaces should be backed by research showing that operators can be effective during takeover scenarios. As these interfaces evolve in vehicle design, federal regulators will need to ensure that innovations do not impair an operator's ability to safely intervene and take over. Added automation and increased cognitive load will require more training and expertise from bus operators so that the benefits of any level of automation can be realized. Without proper training, operators will be unlikely to respond accordingly in a challenging situation, as evidenced by the Uber crash where the minimally trained supervisor was unable to avoid striking a pedestrian (NTSB 2018). We should not develop and implement automated systems without the oversight of trained human monitoring. As suggested by Casner and Hutchins (2019), "*It was only following a concerted effort to educate pilots about the automation, about themselves, and about the concept of a human-automation team that we reached the near-zero crash rate we enjoy today in the airline industry*." Similar work on human-automation teaming in potential automated transit bus and van operations should be conducted.

1

POLICY RECOMMENDATION

Because of the implications on an operator's workload, the US Department of Transportation (US DOT) should further research the added work tasks and potential stresses introduced to transit bus and van operations as automation transitions work from primarily physical operation of a vehicle to supervision and emergency takeover control. Consideration should be given to added mental demands on operators. Regulations on human-machine interfaces should consider what operators will need in the most challenging situations. New training programs based on human-automation teaming research should be developed for bus operators working with automated systems.

Who manages problems when they arise?

As discussed in the previous section, automation may reduce some kinds of incidents, however it will likely create new kinds of incidents that will require human intervention. This may happen more or less often depending on the maturity of the automated vehicle technology and the conditions under which it is deployed and operated. However, it should be expected that **there will be unforeseen situations that extend outside of normal operations**.

Safety on the road

As it stands today, most automated vehicle technology has only been proven in near-ideal environmental conditions. However, the world is anything but ideal. For example, during heavy rains in New York City, an operator managed to safely transport passengers while navigating flooded streets and operating a water-filled bus (Hanna 2021). Furthermore, consider an everyday scene near a bus stop where other cars are navigating and pedestrians are rushing around. Given that transit often operates close to vulnerable road users, it will be critical for automated vehicle perception systems and automated braking to be highly robust. Considerations should be made for determining what appropriate levels of safety will be required and how automated vehicle systems will be federally certified under different conditions.

Furthermore, when there is human-in-the-loop operation, there should be effective and clear communication between the automated vehicle systems and the operator. Given the need to navigate traffic and avoid collisions on the road and with vulnerable road users, operators will need to maintain situational awareness of other cars, cyclists, scooter riders, and pedestrians, especially in high traffic areas. For example, there will be a need to train operators to understand why a bus may have stopped suddenly and to only override when it is most safe. Illustrating the stakes of this issue, one can look to existing examples where operators have overridden automated vehicle systems at the wrong time, such as the previously mentioned case of the autonomous shuttle crash at the Tokyo Olympics. The opposite was true in the deadly 2009 accident involving a Washington, DC WMATA train rear-ended a stopped train due to a malfunction of the automated train control system indicating the track was clear. By the time the operator realized there was a stopped train ahead and attempted to intervene, it was too late. Nine people including the operator died (Wilkins 2010; DiMargo, Tuss, and Stabley 2019).

It is often stated that driverless vehicles could have profound impacts on roadway safety. Since a high fraction of vehicle crashes are caused by driver errors, driverless vehicles have the potential for significantly improving roadway safety if they are effective and deployed in the proper operating environments. The National Highway Traffic Safety Administration (NHTSA) estimated that the total costs of vehicle crashes in the United States was $277 billion annually in 2010 (Blincoe et al. 2015), so pursuing deployment of automated vehicle systems may seem quite valuable. However, reviewing incident data from the last several decades, it is clear that **bus operations are already remarkably safe compared to personal vehicle operations**, with an average of 40 occupant fatalities taking place on all types of buses per year (as opposed to 23,000 per year in light-duty passenger vehicles) (Federal Transit Administration 2021). That said, there are still opportunities to **incorporate novel active safety technologies to enhance driving such that riders—as well as pedestrians and cyclists traveling alongside transit vehicles—continue to travel without incident.**

Though less frequent than personal vehicle accidents, the size and weight of transit vehicles heighten the severity of bus-pedestrian or -cyclist collisions (Nabors et al. 2008). According to the Amalgamated Transit Union, *"one pedestrian is killed each week in the U.S. from a bus blind spot accident."* (ATU 2017). Research has found that turning and maneuvering around bus stops are the most frequent cause of accidents due to low visibility and driver distraction, which is intensified by fluctuating traffic volume (Girbés et al. 2017; Park and Trieu 2014). Technologies that provide assistance in the moment (e.g., driver assist, blind spot detection) already offer drivers increased visibility in these instances, but there remain opportunities to enhance planning and driver experience by indicating the likeliest location and time of potential accidents given historical data and predictive analytics responsive to traffic and weather conditions, a benefit that could extend from transit to other large public utility vehicles.

Safety Onboard

Alongside considerations for conditions outside the vehicle, bus operators also need to manage issues and emergencies that occur on the bus itself. For example, operators must be attentive to the needs of elderly passengers and people with disabilities who require assistance, as transit operations are subject to Americans with Disabilities Act (ADA) requirements. While ADA compliant automated wheelchair ramps and securement systems are in development there remain no industry standards for such systems that require no input from a driver. Additionally, a survey of user attitudes towards autonomous transit operation reveals different aspects of safety concerns (Azad et al. 2019). While respondents reported feeling AVs could benefit on-the-road safety, there was a drop in perceived safety on board. With a bulk of operator duties revolving around managing unpredictable public behavior, the on-board safety of passengers becomes a key safety consideration with AV deployment in transit, particularly if it corresponds with proposals to remove the operator, downgrade them to “monitor” status, or to make them remote.

Even with safety enhancing technologies in place, there remains a need for operators on-board to scan for latent hazards, or threats to safety that aren’t immediately visible to the system or the driver, but that may be predictable to an experienced operator (Young et al. 2010). Toward this end, we highlight the need to avoid over-reliance on automated systems, and instead recognize the importance of transit labor in ensuring the safety of those on- and off-board. New training protocols and requirements should consider how work tasks may shift in light of the introduction of increased safety-enhancing automation and offer instruction to drivers around supervision of such systems. This might involve instruction on computational reasoning often invisible to human workers who may currently be less inclined to take actions that might otherwise reduce risks to driver, riders, and pedestrian safety.

2

POLICY RECOMMENDATION:

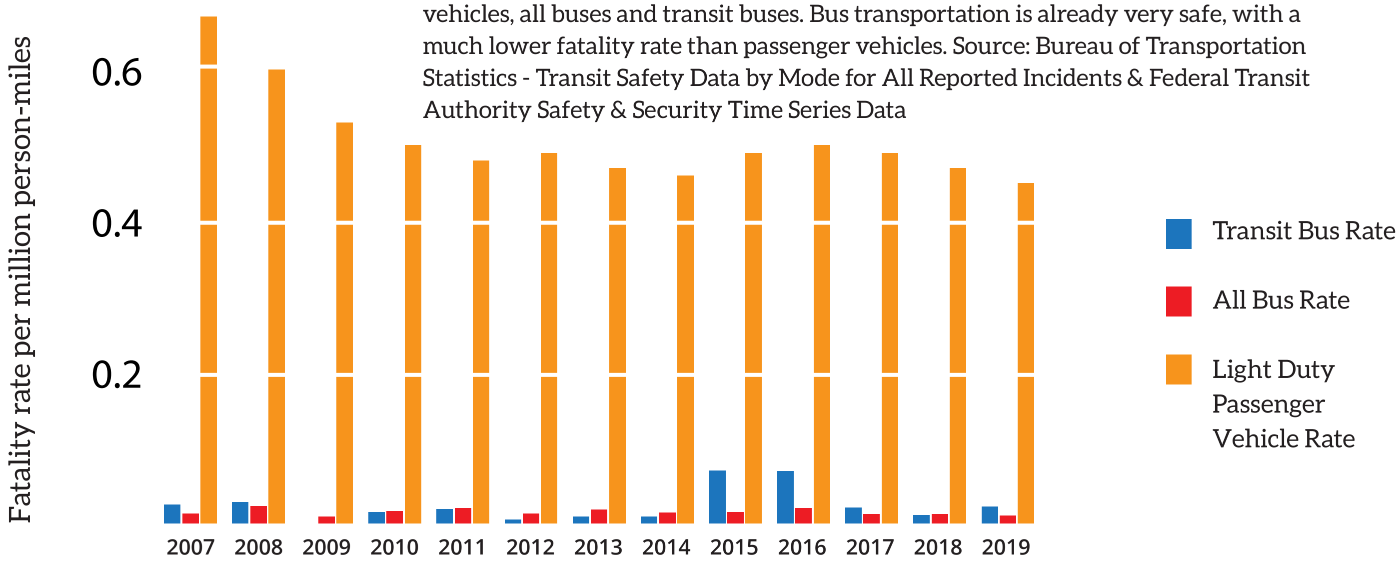
The Federal Motor Carrier Safety Administration (FMCSA) and the Federal Transit Administration (FTA) should support research on active and passive systems that can improve safety on the road and a driver’s ability to maintain safe operations. Research should also be conducted on supporting passenger safety inside of the bus. As new technologies are proven safer, policy makers should reconsider regulations and standards such that technologies can be made available (e.g., allowing cameras to replace mirrors to eliminate blindspots). FTA should also consider grant programs for nimble agencies who may be able to test and adopt new technologies quickly and develop training programs to share with other agencies.

3

POLICY RECOMMENDATION:

The US DOT along with the FTA Bus Testing Program should develop new oversight measures and requirements to ensure safety isn’t degraded as transit systems might consider autonomous buses and vans that are marketed as capable of operating without a human operator on-board.

Figure 4: Occupant fatality rate per million person-miles traveled for passenger vehicles, all buses and transit buses. Bus transportation is already very safe, with a much lower fatality rate than passenger vehicles. Source: Bureau of Transportation Statistics - Transit Safety Data by Mode for All Reported Incidents & Federal Transit Authority Safety & Security Time Series Data



Assessing and Addressing the Problems in Advance

As with all complex systems, both preventable and unforeseen problems will occur as new AV technologies are introduced to bus transit operations. To prevent accidents and to prepare response plans for unforeseen incidents, it will be important for federal regulators, transit operators, transit unions, and equipment suppliers to coordinate safety planning and risk assessment. Today, the FTA requires public transit operators who receive federal funding to prepare Public Transportation Agency Safety Plans (PTASP 2018).

While this model may work well for current transit operations, the introduction of automation technologies in buses will require updates to these safety plans. As a starting point, the FTA has conducted a hazard analysis of Level 0 - 2 automation systems, already highlighting a number of potential new issues that may arise both from the technology itself and from issues in human-automation interactions (Becker, Nasser, and Brewer 2020). The report specifically found that while hazards for buses are often the same as passenger vehicles, the severity and exposure to hazards are higher as transit buses operate in more complex environments with more interactions and proximity to vulnerable road users. The report also found that the presence of a skilled and trained operator offset many of the risks, more so than untrained passenger vehicle drivers. While this suggests that automation systems can be safely integrated into bus operations when skilled operators are present, a hazard analysis has not been done for Levels 3-5 automation in buses. In line with the FTA, our recommendation is for a larger scale hazard analysis to be conducted for higher levels of automation, considering potential hazards with and without the presence of a skilled operator.

Such plans will require transit authorities to gain new knowledge on automation systems and the potential risks and hazards associated with them. While many authorities do have Safety Plans, a recent report by the FTA on the use of risk assessment methods found that many have challenges in completing Safety Risk Assessments (SRAs) (Transportation Research Board and National Academies of Sciences, Engineering, and Medicine 2021). The findings of the report state that while larger organizations may have dedicated safety teams, smaller organizations may not have adequate staffing resources to carry them out and training personnel to complete an SRA can be time and funding intensive. As automation technologies are introduced, transit authorities will likely require additional resources and training to support completing robust SRAs. Additionally, such activities should involve transit operators and their unions as they have specific knowledge on the hazards that can occur on the road and current challenges that operators face.

4

POLICY RECOMMENDATION:

The FTA should conduct a hazard analysis of Level 3-5 automation in transit operations and should support local authorities in conducting their own hazard analyses as part of their Public Transportation Agency Safety Plan. In their analysis, attention should be given to the role of a trained operator in maintaining safety. Frontline works and their unions should be included in these hazard analysis activities. Funding should be allocated to support local authorities, especially those without full-time safety teams. Best practices on training transit authorities in conducting hazard analyses and on updating operator training should be shared among transportation authorities.

Infrastructure applications and considerations

In the context of transit, infrastructure plays a major role in determining the performance of advanced degrees of automation. Small, partially automated vehicles have been preferred for pilot deployments so far, alongside service types that reflect on-demand operations (Azad et al. 2019). There is limited research on larger passenger vehicles, although major bus manufacturer New Flyer (NFI) and Robotic Research have partnered to increase deployment of Advanced Driver Assistance Systems (ADAS) featuring Level 4 automation (including collision avoidance, lane assist and precision docking). According to NFI and Robotic Research, ADAS deployment has the ability to be retrofitted into existing buses. It is also present in a new bus model, the New Flyer Xcelsior AV, which is set to be tested in Connecticut (CTDOT) beginning in 2023. Funded by the FTA's Integrated Mobility Innovation initiative, the bus will operate primarily in bus-only lanes. According to recent research at a state and local transportation agency level, greater infrastructure modification will be needed to improve automated vehicle operation, along with additional guidelines on procurement (Roldan et al. 2020). For example, Tsigdinos et al. (2021) argue for the development of altogether new street types devoted to autonomous transit vehicles, as well as pedestrians, cyclists, and micromobility devices (e.g., networked scooters). Whether dedicated lanes or streets, the infrastructural investment necessary to ensure the safety and performance of buses with automated capabilities will be substantial.

5

POLICY RECOMMENDATION:

The FTA should invest in infrastructure innovations to better support new technologies with a strong focus on data collection and sharing among agencies (e.g. vehicle to infrastructure communications). Collaboration with the The National Transit Cooperative Research Program (TCRB) should be done to develop systems for operators and agencies to report incidents inside the bus and with automation systems. Manufacturers should be included in data sharing efforts.

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Team Description

Our team is composed of a set of experts across the domains of transportation, human-computer interaction, and autonomous vehicle research, all affiliated with Traffic21, a transportation research institute at Carnegie Mellon University. Nikolas Martelaro, Sarah Fox, and Jodi Forlizzi are faculty in the Human-Computer Interaction Institute whose work collectively focuses on perceived trust in automated vehicle (AV) technologies, situation awareness in automated vehicle operation, and the impacts of AI and automation technologies on transit work. As Director of the USDOT Mobility21 University Transportation Center, Raj Rajkumar's expertise focuses on the design and development of connected and autonomous vehicles. Chris Hendrickson, Director of Traffic21 and Stan Caldwell, Executive Director of Traffic21 and Mobility21, work to guide policy as it relates to autonomous vehicles.

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