Human Supervision of Autonomous Vehicle Fleet Operations and Associated Passenger Communications

Preprint

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NATIONAL LABORATORY OF THE ROCKIES

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Human supervision of autonomous vehicle fleet operations and associated passenger communications

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1 INTRODUCTION

The National Renewable Energy Laboratory (NREL) has been actively developing and advancing the concept of automated mobility districts (AMDs) as a pathway to the future of transportation mobility within dense urban settings and major activity centers (Young & Lott 2024). As a U.S. Department of Energy research and development center, NREL studies the mobility trends by which the convergence of automation, electrification, and on-demand services will enable resilient and productive urban environments through the concept of AMDs.

Central to the AMD concept is the operation of multiple autonomous vehicle (AV) technologies with vehicles of different sizes deployed to provide different service modes, all within the integrated operation of the multiple fleets of different vehicles. Figure 1 illustrates this range of vehicle technologies and operating modes the authors believe will flourish in the next five to ten years as AMDs come into existence. In this scenario, fleets small and medium-sized vehicles provide on-demand service for single-travel party "private rides," and medium to large vehicles are dispatched on-demand to service multiple travel party "shared rides" (i.e., shared with individual strangers or two more parties unknown to each other). These demand-responsive service modes will be combined into a comprehensive transportation mobility system that will align with fixed-route bus service and regional high-capacity transit service, as well as pedestrian and micromobility (e.g., bicycle, scooter, etc.) modes. Within the AMD or at its perimeter, all services will typically converge for regional access and first-/last-mile intermodal connections at designated mobility hubs.

This comprehensive automated mobility transportation environment, comprising a "system of systems" – that is a balanced and integrated approached with various vehicle fleets, vehicle sizes, service modes, and technologies - will provide a high service level throughout the urban district or other major activity centers, such as university campuses, airport terminal complexes, or large medical complexes. And when combined with the dominant trend toward deploying AV fleets with electric propulsion vehicles, the energy efficiency benefits and reduced environmental impacts can offer a highly resilient transportation model.

The authors are studying the factors that will determine the nature and configuration of the command-and-control systems and the associated facilities for the range of types, sizes, and complexities of AMDs they envision. This work is part of NREL's Phase IV research of the anticipated implementation challenges for large-scale, multiple-fleet, multimodal AMDs in the coming years. The concepts discussed in this paper explore the authors' initial investigations, currently underway, which will frame the ongoing study of human supervision of and interactions with fully automated systems comprising future AMDs.

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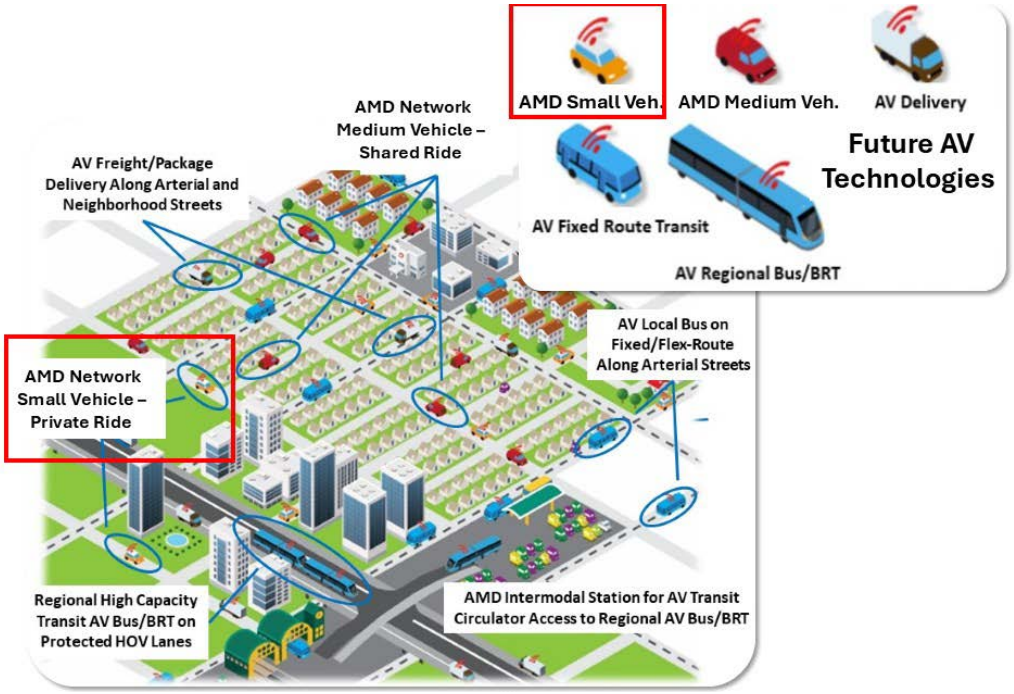

Figure 1. NREL's Automated Mobility District network concept: multiple fleets of different AV technologies will circulate within an AMD and connect passengers to regional transit, with these multimodal services potentially involving different and distinct fleet operating companies.
Figure source: Houston-Galveston Area Council

2 HUMAN SUPERVISION OF AUTOMATED SYSTEM OPERATIONS

The authors have, through early research, advanced a view of automated fleet operational deployment that has compared the control system's functional subsystems with those of automated guideway transit technology utilizing communications-based train control (CBTC) (Lott et al. 2021). These functional control subsystems (represented in Figure 2), comprising the combination of vehicular onboard controls, roadway infrastructure control elements, and the operations control center command and control functions, are integrated into the complete fleet operations control system identified in the diagram as the Automatic Fleet Operations System. These subsystems include both on-vehicle and off-vehicle hardware and software, with communications systems tying everything together.

As indicated in the Figure 2, the focus of this paper is the Automatic Supervisory Dispatch and Control (ASDC) subsystem. This corresponds to the Automatic Train Supervision subsystem in the classic CBTC automated train control system.

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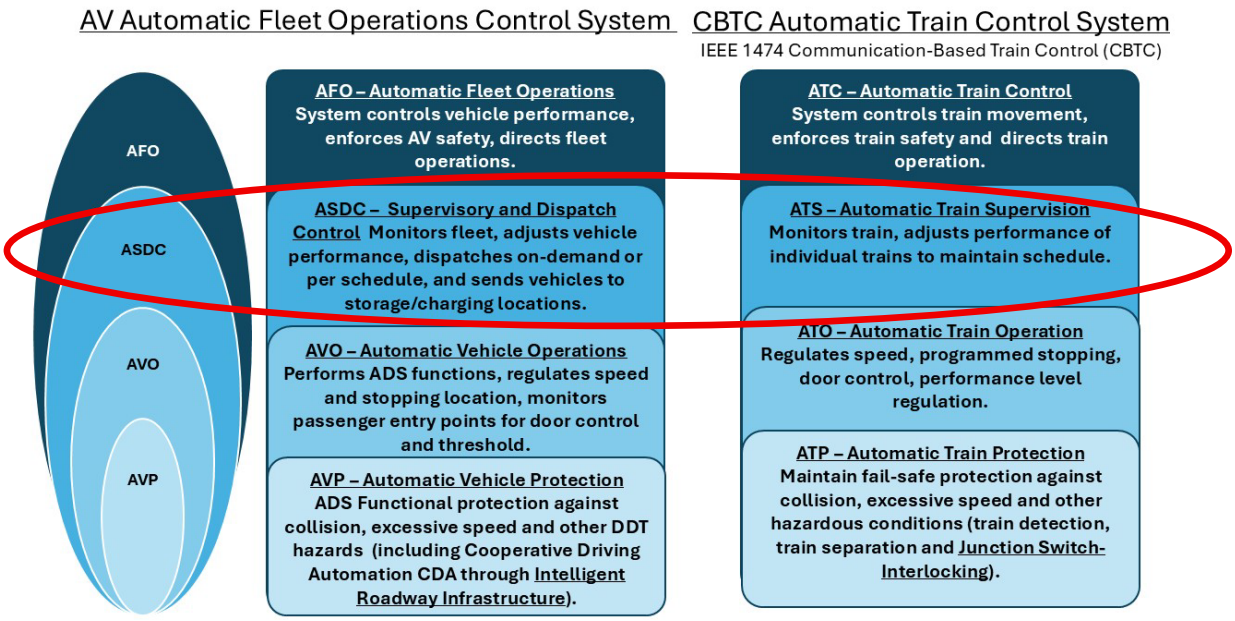

Figure 2. Definition of AV automated fleet operations control system and subsystems based on the functionally equivalent automatic train control subsystems for a fully automated transit system with driverless and unattended trains.

In technical literature and press coverage a large amount of attention is paid to the onboard automated driving system (ADS), which aims to replace a human driver with its array of sensors, machine intelligence, and means of knowing precisely where it is in the roadway network. But as essential as the ADS is, by which most of the functional aspects of driving and safety are performed in each vehicle, the complete automated fleet operations (AFO) system must also include the human-to-machine interface with operations personnel in the facility that is referred herein as the operations control center (OCC).

Figure 3 illustrates how the automatic ASDC subsystem incorporates a fully integrated OCC. Within this OCC, operations personnel continually monitor and occasionally interact with various elements within the automatic fleet operations control system as individual vehicles are dispatched in response to passenger activity. This is referred to as management by exception, in that personnel are present to address issues that arise that are outside the fully automated systems boundaries — whether derived from anomalies of environments, failures of equipment, or needs of riders. Of particular importance is the role of OCC personnel providing a human interface with passengers by responding to passenger inquiries via intercom or video links within stations and in the vehicles. Both aspects of human supervision and oversight of the fully automated passenger transport system are discussed below.

The continuous monitoring of AV fleet operations is typically facilitated by other automated features that continuously report key performance indicators for the fleet to OCC operations personnel. This monitoring is also applicable for individual vehicles when conditions warrant closer scrutiny, such as when an OCC operator makes an inquiry for this information at an operations workstation or when preset thresholds or conditions create a warning flag for operations to address or when a rider requests assistance. When judgment is made by operations personnel that some type of change should be initiated within the normal parameters affecting vehicle dispatch, the operator's control functions typically allow their adjustment of a selected set of command-and-control functions. Examples of this intervention would be an action to hold a particular vehicle at a given location for a period, or a decision made by OCC personnel to remove a specific vehicle from service and dispatch it to a maintenance facility for special attention.

Other aspects of human intervention may involve actions taken by personnel within the OCC to resolve critical operational issues of a specific AV in real time. These interactions are called "remote assistance" and are discussed below in further detail.

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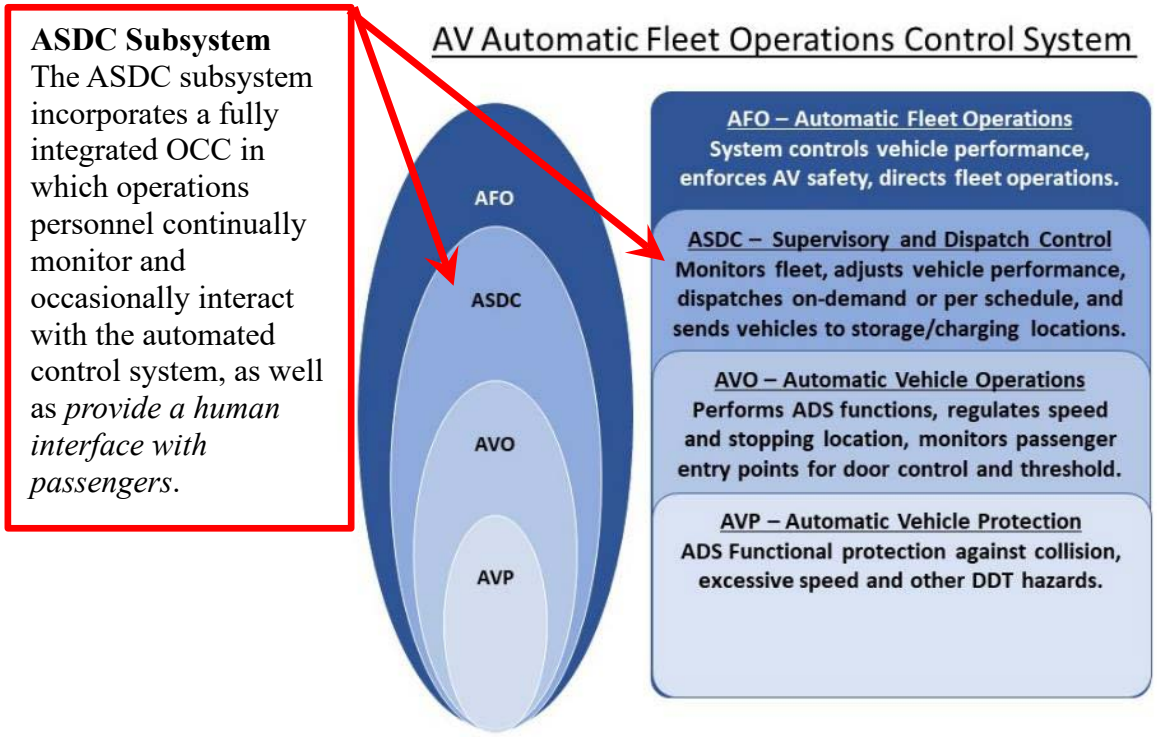

Figure 3. The ASDC subsystem is managed from an OCC, where operations staff monitor the fleet, supervising the automatic adjustments to fleet performance and operations, while also providing remote assistance to individual vehicles when necessary.

3 STRATEGIC LOCATION OF OPERATIONS CONTROL CENTER FACILITIES

The placement of the OCC facilities is traditionally in a location convenient to the main service area of the AMD. This is an important consideration when preparing for the ultimate expansion of the AMD to a large scale, since the OCC involves the management tasks of the primary supervisory functions of the fully automated fleet operations. However, there have been conditions in the early R&D and demonstration pilot phases of relatively small-scale AV transport system deployments in which the primary OCC has been at a location remote from the actual deployment site, perhaps located in a distant city in which one OCC manages multiple AMD deployment through integrated electronic communications. Typically, the circumstances under which remote locations have been incorporated involved a relatively small fleet size of a dozen or fewer AVs in service and the presence of operations personnel onboard each of the vehicles (as a safety driver or attendant) as the vehicles were engaged in passenger service.

An example of a remotely located OCC was during the deployment of the EasyMile shuttles on the Texas Southern University (TSU) campus during 2019–2020. The single shuttle shown in Figure 4 was monitored from the EasyMile headquarters in France, with only the local operations staff on-site at the TSU campus onboard each vehicle as it was in operation along Tiger Walk within the TSU campus in Houston, Texas.

In contrast with the remote OCC approach described previously, Figure 5 shows the placement of the Autonomous Innovation Center facility for the new Jacksonville Transportation Authority's (JTA's) Ultimate Urban Circulator (U^2C). The location of this OCC facility is in the center of the operational service area, as the complete U^2C system will ultimately be implemented—the scale of which is depicted in the figure graphic. Personnel at this facility are currently monitoring and acting to adjust the system performance and operations for the Phase 1 Bay Street Innovation Corridor, called the NAVI transport service, which initiated automated passenger service in June 2025.

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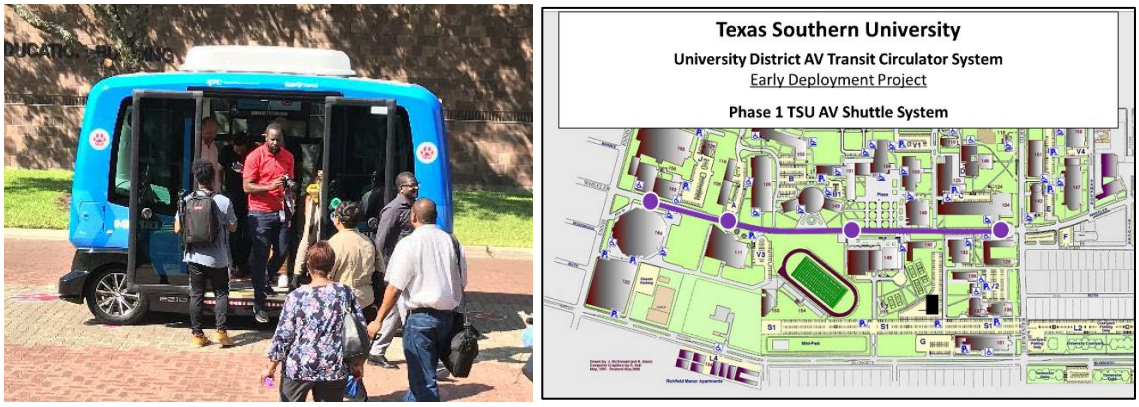

Figure 4. Local operations of the EasyMile shuttles were monitored on-site at the TSU campus in Houston, Texas, by onboard operators. The AV technology vehicle status and operations were also monitored in real time from EasyMile's OCC, located in France. Source: Houston Metro (left), TSU (right)

Figure 5. JTA U²C Combined Phase 1 Bay Street Innovation Corridor and Phase 2 conversion of the existing Skyway system to allow AV technology to operate throughout the larger system.
Source: JTA

The Innovation Center facility is designed to serve as the operations control center for all AV fleets in service within the U²C district, beginning with the new NAVI AV fleet service. This U²C Phase 1 route (shown in blue in Figure 5) is 3.5 miles in round-trip length, connecting downtown Jacksonville with the sports complex (far right). The future Phase 2 route will deploy a different AV vehicle technology that will be manufactured by Holon in their new factory, also located in Jacksonville. This second AV technology is utilizing a different ADS control system and will operate along the existing aerial structures being converted from outdated monorail automated people mover technology to modern AV technology.

With reference to these two examples, the NREL AMD research is investigating the factors determining the OCC location. The possible combination of both on-site and remote OCC locations is anticipated under some circumstances, when factors such as the economics of skilled labor cost and availability at a given site are considered.

If the actions taken by the OCC personnel do not require a physical human presence, human assistance to the automated systems could be effectively and efficiently executed by activating automated processes

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and/or notifying other personnel located on-site, who could directly intervene. The authors have encountered examples of these factors in traffic management operations centers and from fixed guideway OCCs. Many traffic management centers are co-located with emergency dispatch for coordination and communications within the region of which they serve, though during off-peak, overnight periods it is common for these functions to shift to a state-wide center. As the 'feet-on-the-ground' response is handled through either emergency personnel or mobile operations personnel, remote location is not uncommon. For traditional automated people mover systems, typically rail based and frequently encountered at large airports, the OCC is local, allowing personnel to quickly travel to location of any anomaly to assist with passenger management and system recovery procedures. Current trends in the AV industry indicate remote OCCs for large AMDs could be common going forward because of the prevalence of high-speed, reliable telecommunications networks, although on-site OCC has the advantage of human presence when absolutely required. The balance of remote versus on-site OCC facilities has yet to be determined.

4 CO-LOCATION OF OCC FOR DIFFERENT AV TECHNOLOGY FLEETS IN A SHARED FACILITY AT THE AMD LOCAL SITE

Co-located OCCs of various fleets, each with different AV technology and different passenger service modes, into a single facility with oversight by the AMD management authority, is an approach proposed in prior published papers (Lott & Young 2021). This is similar to traffic management centers, 911 call centers, and emergency dispatch having co-located centers within a metropolitan area—where the impacts of any one situation may impact many subsystems, the co-location of central oversight management presents synergistic benefits, and initial incident detection from any of the sub-systems provides direct input to the others.

An integrated OCC would encompass different vehicle technologies of different sizes providing an interconnected mobility service (e.g., one fleet for shared-ride on-demand service connecting at specific locations with a different technology fleet providing larger capacity fixed route service). The AMD management authority may host a single district-level management entity to oversee the multi-fleet operations, or the facility could be provided for each of the different fleet operators to co-locate their OCCs at a single location. In such a co-located OCC facility, there could still be other operations offices within the larger district that operate specifically under the auspices of the individual fleet operators. This is consistent with the model found in the placement of the primary OCCs in large, automated fixed-guideway systems, which are located within the service area of the system but also complemented with small operations command centers/offices that are in proximity to different localized areas of service within the AMD.

For example, within a large medical district that encompasses a dozen major hospitals and outpatient centers, several geographical areas at opposite ends of the large campus may have field support offices from which operations personally can stage and be prepared to respond to the need of any individual vehicle operating in the immediate area, when a presence of a representative is necessary. Such an operations office could be effective for the fleet operator of a given small AV technology providing on-demand service for single party travelers. Operations personnel could be quickly dispatched either to observe and interpret the conditions during problems or incidents, or to physically intervene in the automated operations to take manual control of a vehicle to drive it out of complex conditions in which it is unable to operate under automated or remote operation.

The direct involvement of the AMD management authority in the large-scale operations across all fleets may also be a factor in the day-to-day affairs of the shared OCC—including police and/or fire emergency operations or short-term construction activities impacting normal fleet operations. Emergency situations to be considered include events within the AMD's operational domains (such as a failure of a vehicle blocking a critically important arterial street, or a fire at power substation) or events completely external to the AMD (such as major weather events that impact many vehicles, whether automated or otherwise). When these types of conditions occur, coordination with traditional emergency response will require an urgent and strategic response. This level of coordination across multiple public and private entities is best facilitated through a common operations center. Examples of this sharing of transportation operations centers with emergency management personnel are commonly found in roadway traffic management centers, such as the Houston Transtar facility managed by Texas Department of Transportation—a major traffic operations management center serving the entire metropolitan area of Houston, Texas.[1]

[1] https://www.houstontranstar.org/.

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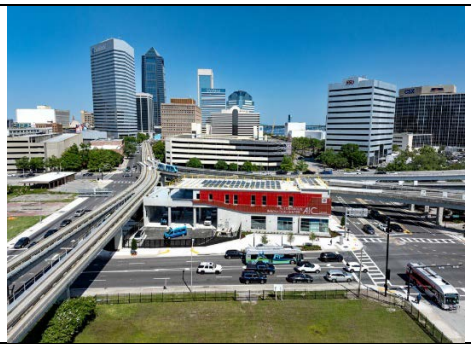
The single OCC facility in Jacksonville is designed to simultaneously monitor and control the operations of multiple AV technologies. It is an example of a co-located OCC for different AV fleets each with different operating modes and correspondingly different Automatic Fleet Operations Control systems, and potentially even involving different fleet operators. The OCC at the Jacksonville Autonomous Innovation Center facility will be supporting the operations of different vehicle technologies with different suppliers of the ADS autonomy "stacks" of onboard software and hardware. With reference to Figure 5, the Phase 1 NAVI deployment that operates in mixed traffic on Bay Street will use the Ford E-Transit passenger vans employing the OXA control system, whereas the Phase 2 AV fleet that will initially operate on the existing transitway structures through the center of Jacksonville will comprise the Holon vehicles that utilize a Mobile Eye ADS control system. Both of these completely different AV technologies will be operationally managed and controlled from the one OCC facility shown in Figure 6— initially operated by JTA's designated U^2C system operations contractor BEEP, Inc. As additional new AV technology vehicle platforms are deployed in the future, JTA intends to also operate them from this OCC facility. At such a shared OCC facility, the coordination of weather impacts, roadway operational incident and emergency events, and other matters that affect all the fleets in operation can be more easily accomplished.

A remote operations monitoring and control facility that is digitally connected to the local common-facility OCC could also be part of the AMD implementation, such as a remote office where the AV technologies engineering staff are located. This approach with connected OCCs allows a deployment concept involving some control and oversight functions being performed remotely, such as assessments of failure trends or operational incidents by the AV technology developers, as well as on-site local operations offices that provide coordination of the response with the local OCC operations personnel that are responsible for the given AV technology fleet at the deployment site. This aspect is discussed further in the next section.

JTA's Autonomous Innovation Center will be managed by BEEP, Inc. As the Phase 2 deployment of the new Holon vehicle technology comes online, the same OCC facilities will service that operati fleet.

This shared-use OCC provides a model for co-location of different AV fleets with different technologies and different operating modes within a single facility.



Phase 1 NAVI Service Ford E-Transit Vehicles at Autonomous Innovation Center Facility

Phase 2 Holon Vehicles To Be Manufactured in Jacksonville

Figure 6. Jacksonville Transportation Authority's Autonomous Innovation Center facility will serve as the OCC for the two different AV vehicle fleets of Ford E-Transit vans and the new Holon vehicles.
Source: JTA

5 ROLE OF OCC PERSONNEL PROVIDING REMOTE ASSISTANCE TO AVS

One of the key roles of operations personnel working in the fleet operations OCC is to perform human interactions with specific autonomous vehicles using the vehicle communications and control functions provided by the system-wide AFO system. As shown in Figure 3, the AFO is the umbrella command and control system for all subsystems and vehicles operating within the entire fleet for each independent vehicle

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technology in service, including the human interfaces that occur within the automated supervisory and dispatch control functions.

Within the AFO, the ASDC subsystem has the capability to provide remote assistance to fleet vehicles requiring assistance to navigate situations outside of their operational design domain. Through this human-facilitated assistance, the vehicle is allowed to maneuver through or around a roadway environment that would otherwise be against the safe driving rules and/or protocols of a specific technology's ADS.

An example of this permitted violation of the programmed operational criteria would be for an AV to move into the adjacent reverse directional flow lane to drive around an object of vehicle blocking progress through the normal travel lane of the AV fleet operations. The Society of Automotive Engineers (SAE) Industry Technology Consortia, Automated Vehicle Safety Consortium (AVSC) has prepared a Best Practice industry guideline (SAE International 2023) that describes this human interaction:

> Remote assistance *"is one approach that can help to address the challenges for operating ADS in such scenarios. The ability to provide timely remote support to vehicles can help overcome some situational challenges for the ADS to continue the trip, such as handling ambiguous scenarios."*

One of the authors experienced this kind of operational incident while riding within an uncrewed AV operated by Cruise while in Austin, Texas, on June 16, 2023. The incident and the remote response of the OCC personnel to provide remote assistance to the stalled vehicle is documented in a published technical paper (Zhu, Lott & Young 2025). The successful remote assistance by OCC personnel provided to an AV stopped in an active traffic lane behind a line of illegally parked vehicles. The vehicle was "permitted" by the human intervention to move into the opposing directional traffic lane when the vehicle sensors detected there were no vehicles approaching from the opposite direction. It traveled several hundred feet around the blocking vehicles before moving back into the correct travel lane to continue its assigned trip.

This example illustrates that even sophisticated AV technologies must have design provisions for human interaction with the vehicle by remote assistance that provides the vehicle permission to take exception to the programmed rules. There are indications from AV developers that different approaches to providing this remote assistance can be found within the ADS of the various AV technologies. One is to allow operations personnel in a remote OCC to take control of the vehicle and remotely "drive" it around the problem area or incident—a methodology often referred to a "tele-operation." Another approach that has been described is to have the OCC personnel give the vehicle a series of "breadcrumbs," as points along a permitted travel path by which the stalled vehicle can circumvent the conditions that have caused it to stop. As the industry matures, these various approaches and methodologies of providing remote assistance to individual AVs will be tested and refined. This vetting of the various means and methods of assistance will determine the criticality of other factors—such as command and control communications latency and the sufficiency of strictly the vehicle's own sensing and perception equipment without other supporting systems such as intelligent roadway infrastructure.

Another scenario that would typically involve human intervention would be a failure of a given vehicle's ADS equipment or other supporting control system elements that bring the vehicle to a complete stop. These types of failures would require operations personnel to physically travel to a stalled vehicle, though these will likely be rare occurrences. However, with the expansion and scaling of fleet sizes in large-scale AMD deployments, these incidents could frequently occur, possibly even daily. When this type of failure occurs in an active travel lane, the fleet operations person would often need to manually move the AV to an appropriate stopping point that is out of the flow of traffic. For automated fixed guideway transit systems, this type of operations personnel is typically called "recovery personnel." They are able to travel to any location within the automated transport system's service area to address a stalled vehicle and move it if needed.

5 PASSENGER COMMUNICATIONS FROM OCC

Passenger communication in manned systems is typically handled by the driver or vehicle attendant. Use of electronic systems for announcing stops and other general travel information is also common, but any customized or ad hoc communication has typically been handled by local personnel—typically the driver. As AV systems remove the on-board presence of the driver, the communications function with the passenger, particularly for ad hoc communications, will become necessary in response to the passenger needs, or in situations where normal transport is disrupted. In these situations, prompt and clear communication with the passenger(s) is critical for safety and comfort.

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Further, when multiple parties are riding within the same vehicle, the driver or attendant has also served as the authority figure for maintaining safety and security, as well as resolving any issues that may arise from multiparty travel. Addressing these functions in the absence of a physical driver or attendance is under the domain of the ASDC within the OCC. The functions that address these concerns may be digitally operated, or even remote, but the responsibility for oversight (ensuring it is carried out properly) remains within the ASDC purview.

Communications functions are discussed in three areas—traveler initiated, operations induced, and multiparty oversight.

Traveler-Initiated Ad Hoc Communication

Traveler-initiated ad hoc communication may be as simple as the traveler asking for assistance with HVAC controls or advice on restaurants or as serious as notification of critical medical conditions (e.g., heart attack or stroke) or detection of malfunction (e.g., the smell of smoke). The simpler communication requests may be handled through customer service call buttons or even AI assistants (both of which are already appearing in industry practice).

The need for direct emergency response is noted in other forms of automation such as elevators— in which it is standard practice and embedded in standards that some type of direct line-of-contact is required with someone capable of dispatching emergency response. So, too, in an autonomous vehicle the need for travelers to request and obtain direct support from operations personnel would be expected. The interface may start with a standard customer support call but would need to be escalated if the traveler indicated the issue was life threatening. Such support would ultimately be managed through the ASDC OCC personnel, as well as the necessary interaction with emergency response personnel (emergency medical personnel, firefighters, police) to address the situation.

System-Induced Ad Hoc Communication

OCC personnel are also responsible for ad hoc communication in response to system-induced changes. These may be as simple as a rerouting the vehicle because of an accident to as complex and urgent as needing to direct passengers to safety in the event of an imminent weather threat, fire along the route, or even large crowds, mobs, or active shooters. As with traveler-induced ad hoc communication, a portion of this may be managed through normal customer service or AI capabilities, but, particularly for any health-threatening emergency, direct contact with human personnel for direction is essential and falls to the ASDC OCC personnel responsibility.

Multiparty Oversight

Multiparty oversight refers to the discomfort and potential threat imposed when strangers share a confined space for an extended period. This first came to prominence when elevators operators were removed, and parties began to share building elevators, unsupervised, and without attendants. As a result, a study of proxemics ensued to characterize expectations and behaviors of unacquainted humans in proximity (Hall 1966). The general observations of proxemics include:

- Humans are comfortable with family and friends within 18 inches to 4 feet.
- Casual and professional relationships are comfortable from 4 feet to 10 feet.
- Typically, strangers are comfortable 10 feet or greater in proximity.

Elevator rides, which are typically 1 minute or less, require unacquainted people to be in close proximity for short periods of times. In the case of elevators, even though riders may not be acquainted, being in a common building implies some form of shared purpose—either a common employer, residence, shopping preference, or generally need to access similar services—all of which lessens the aspect of a "complete stranger."

The advent of completely unattended robotic mobility services will further push the time boundaries of sharing a space among complete strangers with multi-party rides. Current micro-transit rides typically average 3 miles, so within urban areas, shared ridership (compulsory with most micro-transit services) typically requires strangers to share a common vehicle for 5 to 10 minutes on average. In these circumstances, the driver (or attendant) provides oversight and management of unfamiliar parties. On larger vehicles, such as buses and train cars, the presence of multiple parties (3 or more) also provides a form of "safety in crowds." At the time of writing, no AV taxi or microtransit shuttle operation with unattended service has offered multiparty service on a large scale that provides significant experience with this aspect of human interaction for multiparty oversight functions.

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The Morgantown, West Virginia, personal rapid transit (PRT) system, which began service in the late 1970s, was one of the first to deal with the issue of personal safety. Its vehicles, which hold a maximum of 21 people (including persons standing), are equivalent in size to a large van or short bus. As a PRT system, the vehicles transport individuals and small groups of travelers (typically students at West Virginia University) from one of its five stations to another with no intervening stop—functionally the essence of PRT. This mode of operation maximizes throughput during peak demand and minimizes user wait time. However, during off-peak periods, the operations of the system are changed for safety and comfort reasons. If the PRT operations mode were continued into the evening hours, a rider may be on the PRT vehicle with a stranger for a prolonged period—possibly presenting a threat. For this reason, soon after opening, the operation during off-peak hours was changed to function as traditional shuttle operations in which the vehicle stopped at each station, minimizing unsupervised time with a possible stranger, and providing opportunity to disembark at every station.

Methods to provide security and oversight for multiparty rides are yet to be fully established, but methods (available from parallel disciplines) include:

- Noncompulsory ride-sharing
- Larger, roomier vehicles
- Physical partitions, separating seating areas within vehicles
- Social profiles created by riders for digital trust similar to social media provides (unprecedented for public transit modes)
- Education—use of escape/control button/mechanism to end ride early
- Digital third-party presence or virtual third-party presence
- Conspicuous monitoring through video and audio ("You are being watched")
- Multiple party service—encourage multiparty (>2) ride-sharing (safety in a crowd)
    - Two parties may be uncomfortable, three or more provide "crowd safety"
- Additional AI solutions that project both surveillance as well as security.

6 CONCLUSIONS

Advances in AV technology and expanded operations by early developers set the stage for AMD deployment in major global cities in the near to medium term. NREL's AMD research has reached the following conclusions about the systems, essential functions, and optimal configuration of supervisory systems and facilities needed to support an AMD, and in particular the role of humans in large AV fleet operations and passenger communications.

1. Future automated transport fleets operating within AMDs will need on-site or near-site command and control facilities. The authors envision that OCCs will manage various vehicle types, sizes, and operational modes, including on-demand, fixed route service, connecting to large transport vehicle services by which these AMDs are accessible from the edges of the surrounding metropolitan area.

2. An OCC serves as an integrated command and control framework through which vehicle-fleet systems operating in the AMD are managed. Within the OCC, human operators can monitor a range of situations from overall fleet activity at the system level to the automated dispatch of individual vehicles in response to passenger demands. It is this facility where the main interface between human operators, the automated system, and passengers occurs, as well as between fleets of various automated vehicles. OCC operators can provide remote assistance to individual AVs, which become "stuck" within unexpected traffic operating situations to provide either human driving of the vehicle or human guidance to the ADS through or around the problem. When co-located within an operational area, an OCC can coordinate ASDC subsystem functions to enable real-time human oversight and better coordination of transport services.

3. Direct involvement of the AMD management authority in the daily multifleet OCC operations helps integrate roadway traffic management (i.e., both AV and conventional nonautomated vehicle operations), as well as construction management, inclement weather response, and emergency responder/police support services.

4. Operations personnel within the OCC are also responsible for providing audio and video communications with transport system passengers onboard vehicles to assist them in ways previously accomplished by the human driver or attendant onboard the transport vehicle. Typical conditions warranting these operator-to-passenger communications can be characterized

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as (1) traveler-initiated ad hoc communications, (2) system-induced ad hoc communications, (3) multi-party oversight (ensuring passengers feel safe and secure).

Societal norms for multi-party large capacity unattended vehicle operation exist, having precedent in train-based automated people mover systems, however multi-party small-vehicle automation has little precedent short of elevator operations which are typically limited in time duration with multiple unacquainted parties within a common building. This latter area remains a new frontier for society and will require additional focus in future research. Future AMD research will monitor and report best practice with respect to the functional implementations of OCCs, as well as passenger interfaces. Future research will characterize critical data exchange between AV fleets and broader municipal systems for safe and efficient AMD operation.

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