Automated Mobility Districts - A Conceptual Definition

Preprint

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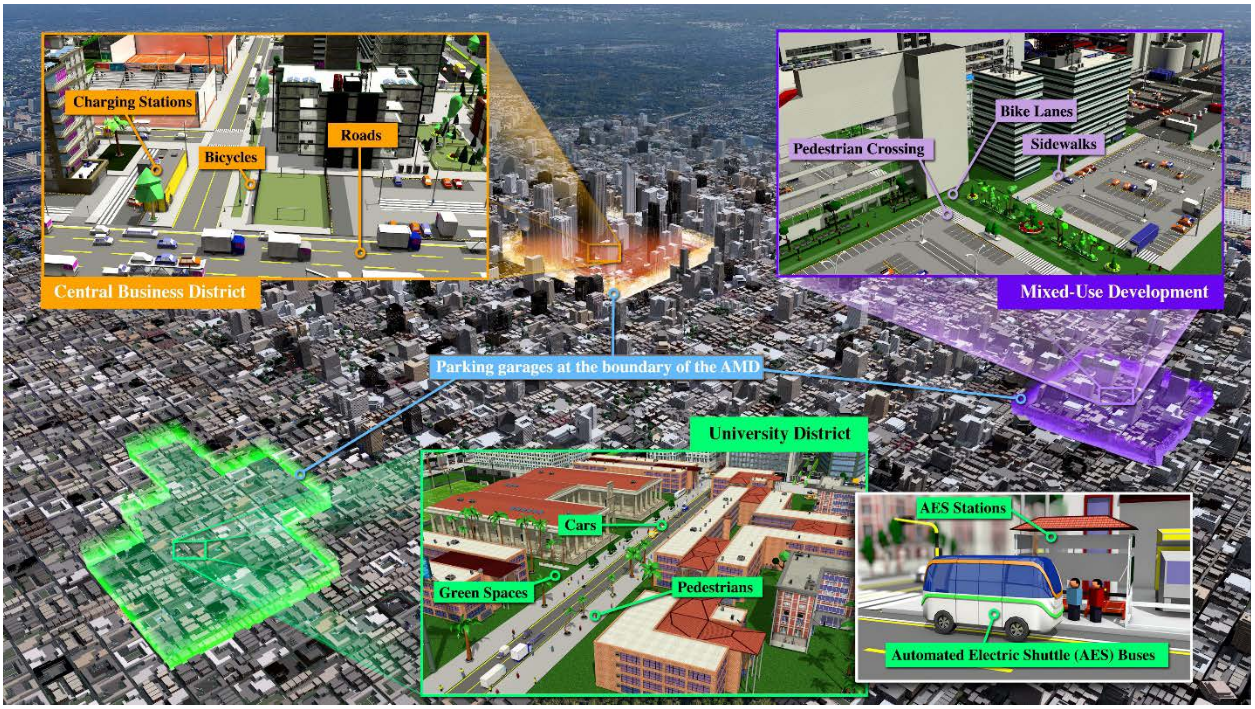

Source: National Renewable Energy Laboratory

Automated Mobility Districts – A Conceptual Definition

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An automated mobility district (AMD) provides for the movement of people and goods within a district through the use of fleets of roboticized vehicles as the primary mobility system. The concept of an AMD has precursors deployed in a few places around the world, in which circulation within a dense urban district such as a business and residential center or a major activity center like an airport terminal complex is accomplished using fully automated transport system(s).

Figure 1 illustrates the functional concept of how a dedicated, fully automated transport system can provide both mobility through internal circulation and connections to intraregional transit and other modes.

A real-world example of this concept of a fully automated circulation system that also connects the entire district with regional high-capacity transit is found in several of the urban business and residential districts of Singapore, as shown in **Figure 2**. This circulator system connects to a major station along the Singapore metropolitan rail system.

Over the last 50 years, this and similar examples of fully automated circulation transport systems have been deployed around the world, and almost all operate on dedicated “guideways” and not along streets in mixed traffic. These dedicated transitways are typically grade-separated from the surface traffic within the district, as can be seen in the photo where the transitway is above the treetops. These early forms of AMDs are very expensive to build.

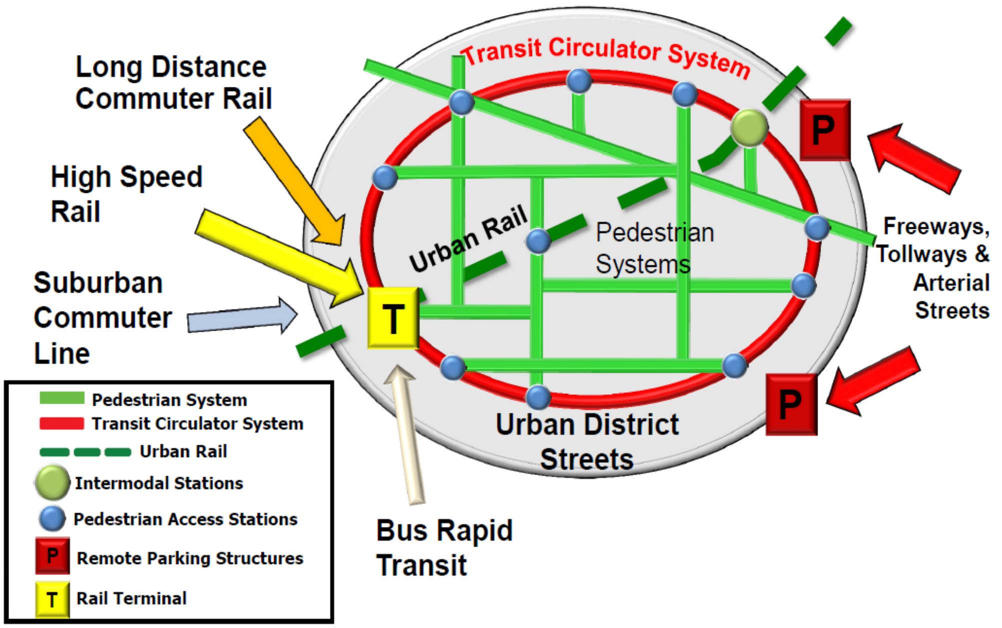


Figure 1. Internal district transport can accomplish mobility with automated circulator systems that also connect to high-capacity regional transit at integrated intermodal terminals.

Source: J. Sam Lott

Figure 2. A precursor of an AMD is found in the Sengkang business and residential district in Singapore, where the Mitsubishi Crystal Mover technology is now operating.

Source: J. Sam Lott

Automated/Autonomous Vehicle Technology Ushers in a New Age

A new age of transportation technology has dawned in the 21st century through which fully automated transport systems will become a reality using existing roadway infrastructure, avoiding high-cost, grade-separated transitway facilities. This technology transformation will allow automated mobility to flourish on a much larger scale than was possible with automated, fixed-guideway transit systems. (Dedicated facilities separate from other traffic may still be used in some locations for high-throughput, critical connections, but are not a prerequisite for automated operations.) **Figure 3** illustrates how multiple automated/autonomous vehicle (AV) fleets will circulate with unmanned, Level 4 automation within AMDs—a spectrum of automation that encompasses multiple vehicle technologies and service modes.

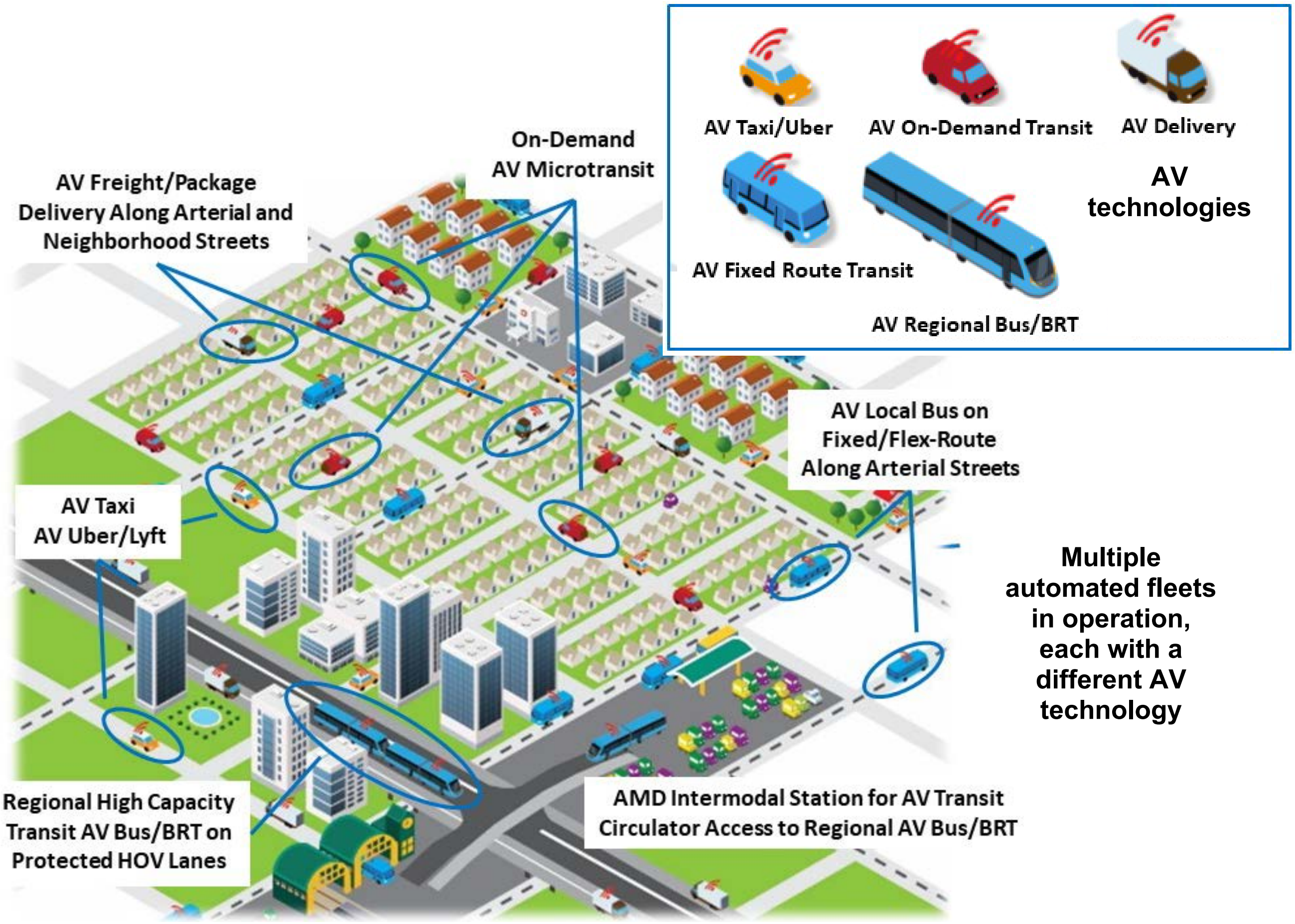


Figure 3. Fleets of AVs circulating within an AMD and providing access to a nearby regional transit intermodal station are managed by different operating companies.

Source: Houston-Galveston Area Council

In the near future, multiple AV fleets may soon begin to be deployed and operated within urban districts in a form that we refer to as an AMD. Each fleet will operate within the same space along the surface roadway network encompassing various service modes, providing the goal of automated mobility through:

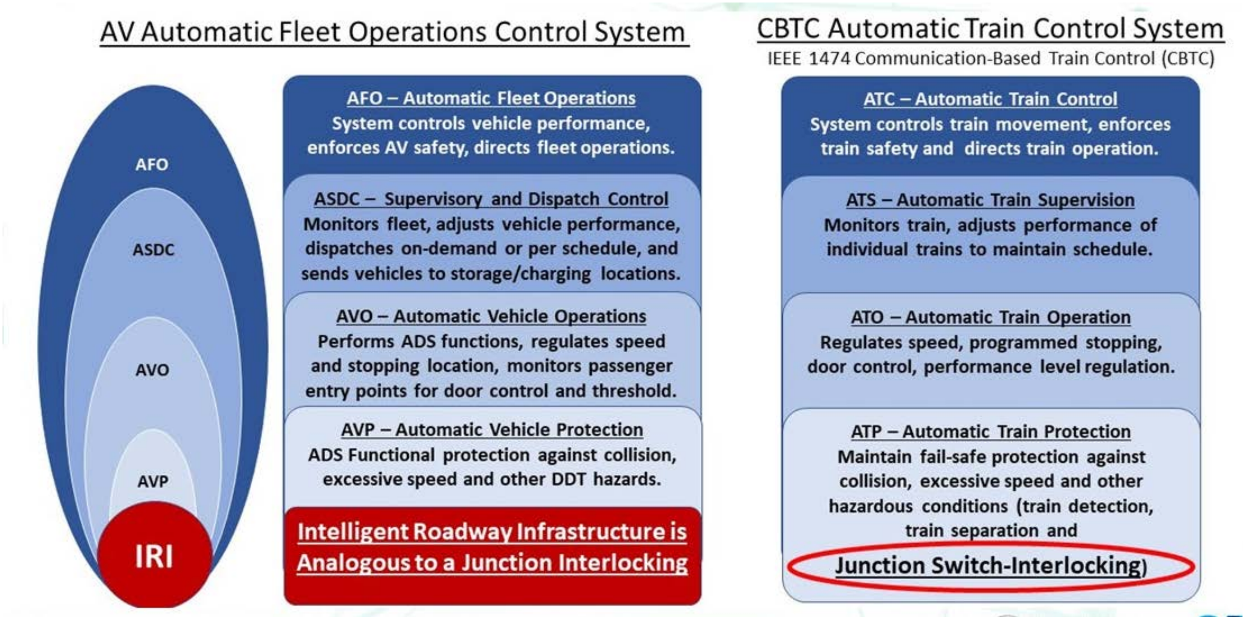
- Fixed-route transit service

- On-demand transit/microtransit service
- Ride-hailing/curb-to-curb car service
- Cargo and package delivery service.

As illustrated in Figure 3, AMDs will be served by multiple fully automated AV fleets—each with a different vehicle technology platform and a uniquely different automated driving system technology. And in this future world, AV buses can also serve as the high-capacity interregional transit technology to which the AMD's AV circulation systems provide first-mile/last-mile connections.

The Role of Intelligent Infrastructure

An AMD will encompass a "system-of-systems" operating environment in which the fleet vehicles will communicate not only with their individual fleet's supervisory/dispatch system and other vehicles in their fleet, but also with intelligent roadway infrastructure (IRI). **Figure 4** illustrates the associated subsystems that encompass not only the AV fleet automated control subsystems, but also the IRI—a concept based on the lessons learned from the last 50 years of automated guideway transit systems (to the right in Figure 4).



AV Automatic Fleet Operations Control System

AFO – Automatic Fleet Operations
System controls vehicle performance, enforces AV safety, directs fleet operations.

ASDC – Supervisory and Dispatch Control
Monitors fleet, adjusts vehicle performance, dispatches on-demand or per schedule, and sends vehicles to storage/charging locations.

AVO – Automatic Vehicle Operations
Performs ADS functions, regulates speed and stopping location, monitors passenger entry points for door control and threshold.

AVP – Automatic Vehicle Protection
ADS Functional protection against collision, excessive speed and other DDT hazards.

Intelligent Roadway Infrastructure is Analogous to a Junction Interlocking

CBTC Automatic Train Control System
IEEE 1474 Communication-Based Train Control (CBTC)

ATC – Automatic Train Control
System controls train movement, enforces train safety and directs train operation.

ATS – Automatic Train Supervision
Monitors train, adjusts performance of individual trains to maintain schedule.

ATO – Automatic Train Operation
Regulates speed, programmed stopping, door control, performance level regulation.

ATP – Automatic Train Protection
Maintain fail-safe protection against collision, excessive speed and other hazardous conditions (train detection, train separation and Junction Switch-Interlocking)

Figure 4. Systems-level comparison of control subsystems between AV transit and communications-based train control for automated fleet operations. IRI is analogous to guideway junction switch interlocking.

Source: J. Sam Lott

This AV system-level control is compared to the automatic train control system used in automated guideway transit technology, particularly that of communications-based train control (CBTC). Drawing from the safety principles, analysis methods, and risk assessments of CBTC systems, comparable functional subsystem definitions are proposed for AV fleets in driverless operation. With the prospect of multiple AV fleets operating within a single AMD, the criticality of protecting roadway junctions requires an approach like that of automated fixed-guideway transit systems, in which a guideway switch zone “interlocking” at each junction location deconflicts railway traffic, affirming safe passage.

The analogous AV protection includes the IRI that enhances the safety subsystem functions within each vehicle. The infrastructure-based safety system comprises fail-safe equipment that monitors roadway intersections and junctions, communicates traffic signal status, perceives and communicates alerts, signals to AV-connected vehicles concerning potential unsafe conditions, and performs related primary safety functions. This approach to AV protection at busy and complex roadway intersections performed by local roadside equipment dedicated to protecting each roadway intersection provides an additional layer of safety beyond solely vehicle-based AV controls. The intelligent infrastructure also provides a higher level of performance of AV traffic on the intersection approach when it allows vehicle to “see around corners.” This level of infrastructure-enabled functionality, referred to as “safety-affirmative signaling,” means not just following green lights and green arrows, but affirming that no other traffic is failing to yield right of way. Further, the sensing and perception of IRI will provide equitable benefits to all traffic, including non-automated vehicles and vulnerable road users

The authors have presented this safety system concept to the industry in a paper titled “Safe Operations at Roadway Junctions - Design Principles from Automated Guideway Transit.”[1] The paper was selected by SAE International as one of the best papers at the SAE/AUVSI 2021 Business of Automated Mobility (BAM) Forum and was chosen for publication in the 2022 *SAE International Journal of Advances and Current Practices in Mobility.*

Ongoing IRI Research

AV technology is quickly maturing, along with active corresponding research on IRI, with the objective of equipping infrastructure to perceive the complete traffic operational environment and communicate in real time to vehicles the requisite sophisticated information. The ability to provide safety-affirmative signaling would complete the interlocking principle of CBTC and would bring performance and safety to complex intersections where AV transit fleet service is most needed, as well as safety benefits to traditional, non-automated vehicles.

Research currently underway at the National Renewable Energy Laboratory (NREL) to implement functional infrastructure perception and control (IPC) is motivated by improved performance (travel time), safety (reduced collisions), and energy efficiency (less fuel burned and minimized production of greenhouse gases). IPC is intended not only for roadway and intersection applications, but also to inform buildings and the grid to better manage vehicles, their charging, and their integration into the built environment. The NREL IPC project presents an open-source framework, architecture, and supporting technology to implement IRI, addressing critical issues such as fusion of data, reliability, standardization of data interfaces, and confidence of detection. The framework is informed by previous experience in U.S.

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[1] J. Sam Lott, Stanley Young, and Lei Zhu. 2022. “Safe Operations at Roadway Junctions - Design Principles from Automated Guideway Transit.” *SAE International Journal of Advances and Current Practices in Mobility* 4 (1): 260–269. https://doi.org/10.4271/2021-01-1004.

Department of Defense research, namely in the use of radar to detect, identify, and track aerial threats. These principles involved in air defense, combined with the principles of CBTC junction safety, provide a pathway to develop IRI functionality that lays the foundation for scalable AV fleet operations within dense urban developments and their very complex multimodal operating environments.

The NREL IPC framework is illustrated in **Figure 5**. When IRI is implemented to drive connected communications between automated vehicles and infrastructure, it will fulfill what SAE International and the U.S. Department of Transportation refer to as cooperative driving automation, in which AV fleets operating throughout the district roadway network inform and respond to communications from the IRI. This in turn will allow the IRI to maximize safety, orchestrate the efficient overall roadway system's operations (of both AV and non-AV traffic), and optimize the AMD's environmental sustainability.

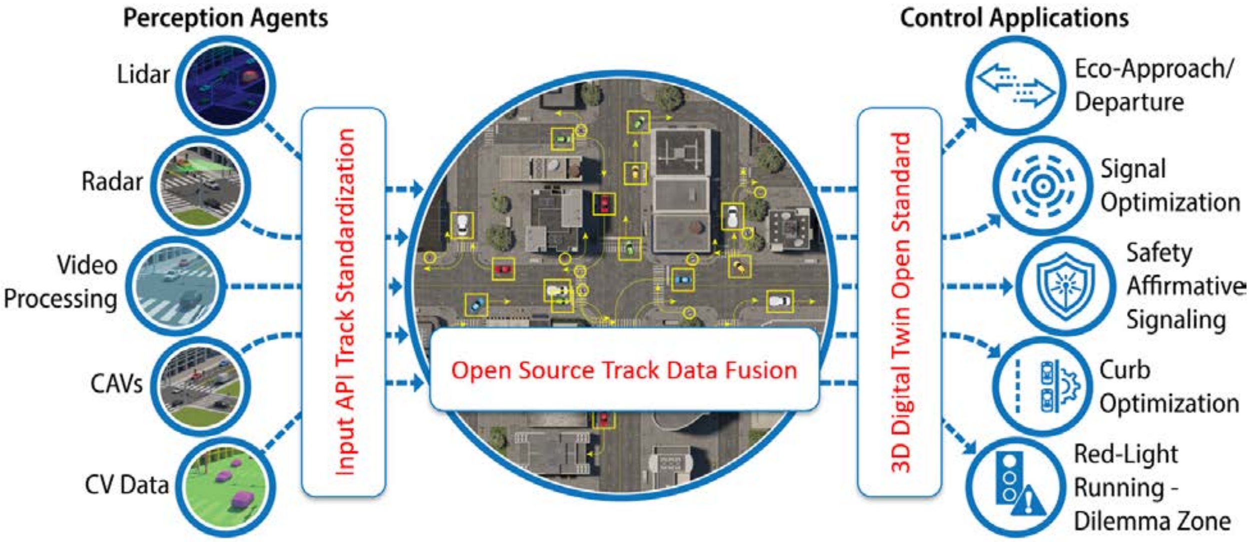

Figure 5. Conceptual function of the cooperative perception engine.

Note: The list of control applications on the right is representative only and not exhaustive.

Source: NREL

The perception agents shown on the left side of **Figure 5** include sensors that track objects such as vehicles, pedestrians, bicycles, micromobility devices, and wheelchairs, as well as agents that relay such information about themselves or other objects in their environment, such as connected or automated vehicles (CAVs). A CAV communicates in real time its identification, position, and velocity through a basic safety message or other protocol. A CAV may also cooperatively report information about itself and objects the vehicle perceives. Connected vehicle data represent an emerging data feed from automotive original equipment manufacturers. These data provide vehicle position and velocity information on a significant subset of vehicles on the roadway, but with significant latency because they pass through the cloud before reaching the IRI equipment.

On the far right of **Figure 5** are control applications enabled by this open framework, which are envisioned for a typical roadway intersection with complex multimodal operations. The applications include classic signal optimization, red light running detection, dilemma zone detection and minimization, and safety-affirmative signaling. In addition to traffic control at intersections, such an IPC framework could be used for curbside management at busy pickup and drop-off zones, as well as energy applications such as eco-approach and departure.

For robust, resilient, and safety-critical applications such as safety-affirmative signaling, IRI frameworks must incorporate some level of redundancy and assess accuracy of the overall digital operating picture (referred to as the digital twin). Such systems need to continuously self-monitor system health and calibrate the system as needed. Lastly, the IRI needs to communicate all such information to participants so that when the IRI ability degrades (e.g., weather, sensor failure), the overall system of systems can transition to safe operating modes (slower speeds, more dependent on individual vehicle sensors). Such an IRI system will require multiple sensors with overlapping fields of view, and ingest available CAV and connected vehicle data for continued validation and calibration.

This expanded field of perception provided by IRI capabilities would address one of the most common types of accidents that AV technology is experiencing in early deployments—that of the vehicle being rear-ended by human-operated vehicles moving at higher speeds. Providing enhanced perception through IRI of all traffic on each approach to an intersection will ultimately allow CAVs to safely operate at higher speeds on their specific intersection approach, no matter how complex the operating environment may be. This integration of IRI ultimately provides higher-speed, safer, and more resilient operation for CAVs, addressing the well-documented issue of unsafe conditions of CAVs slowing to speeds well below the flow of other traffic.

NREL Publications on Automated Mobility Districts

A series of reports and published papers highlights insights from the ongoing research and looks forward with a broad view of how automated mobility will be deployed in dense urban environments over the coming decades. They include:

The Automated Mobility District Implementation Catalog: Insights from Ten Early-Stage Deployments – A report that follows 10 early deployments of automated mobility/transit/shuttle projects drawing broad insights from common issues such as the dangerous tendency of reducing speed in complex multimodal environments.

The Automated Mobility District Implementation Catalog, 2nd Edition: Safe and Efficient Automated Vehicle Fleet Operations for Public Mobility[2] – A report covering AMD demonstrations and deployments from 2019 through 2022.

An associated overview webinar presentation of these findings is also available online. This overview is provided as a 15-minute executive summary presentation and a full 40-minute presentation on the NREL Learning YouTube channel through the following links:

- The Future of AV Transport in Automated Mobility Districts - Executive Summary

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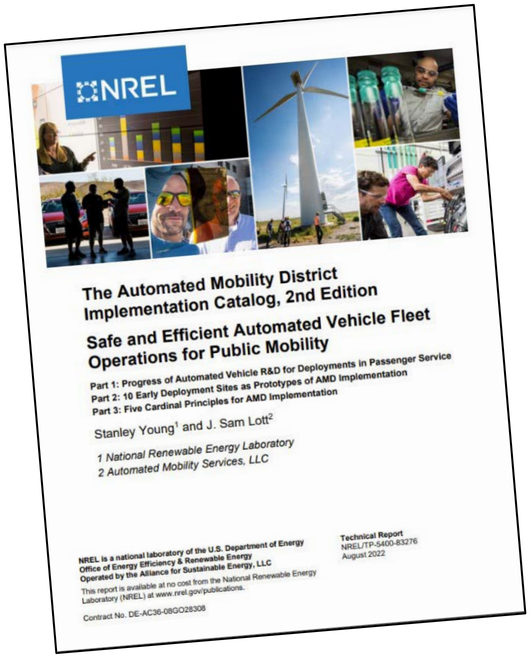
[2] Stanley Young and J. Sam Lott. 2022. *The Automated Mobility District Implementation Catalog, 2nd Edition: Safe and Efficient Automated Vehicle Fleet Operations for Public Mobility*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-83276. https://www.nrel.gov/docs/fy22osti/83276.pdf.

- The Future of AV Transport in Automated Mobility Districts

Research in the field of AMDs and the related technologies and AI perception of IRI continues at NREL. The new phase of work is addressing the complexity of on-demand dispatch operations for fully automated microtransit services when battery-electric propulsion systems are the norm for all of the AVs in the operating fleet. A third edition in the AMD Implementation Catalog is anticipated to be published by NREL in late 2024.



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The Automated Mobility District
Implementation Catalog, 2nd Edition

Safe and Efficient Automated Vehicle Fleet
Operations for Public Mobility

Part 1: Progress of Automated Vehicle R&D for Deployments in Passenger Service
Part 2: 10 Early Deployment Sites as Prototypes of AMD Implementation
Part 3: Five Cardinal Principles for AMD Implementation

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