Vehicle Automation Benefits and Challenges for Passenger Transport System Beyond Automated Driving

ASCE ICTD – 2025

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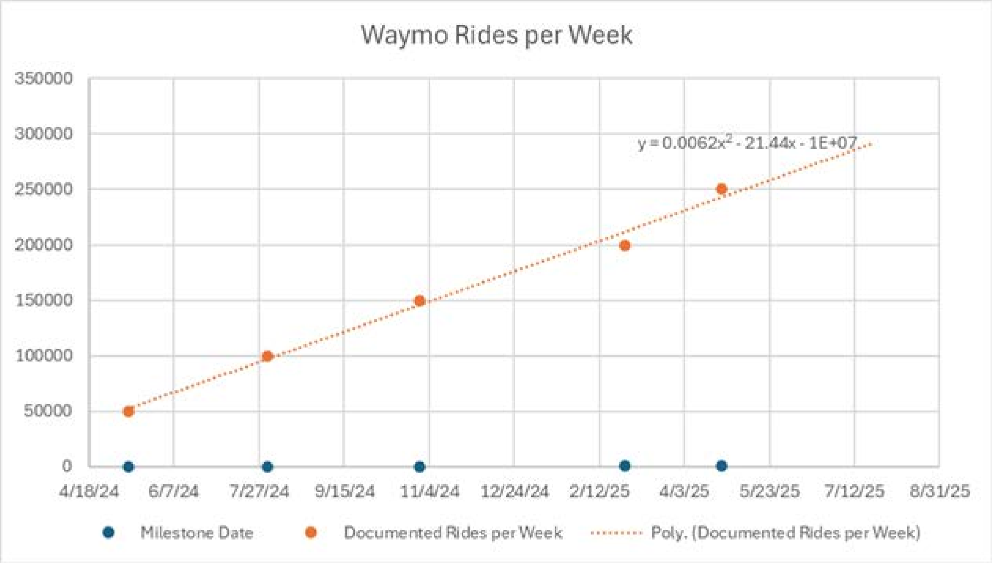
Photo by Werner Slocum, NREL 74763

Leading U.S. Firms in Automated Driving System (ADS) Development

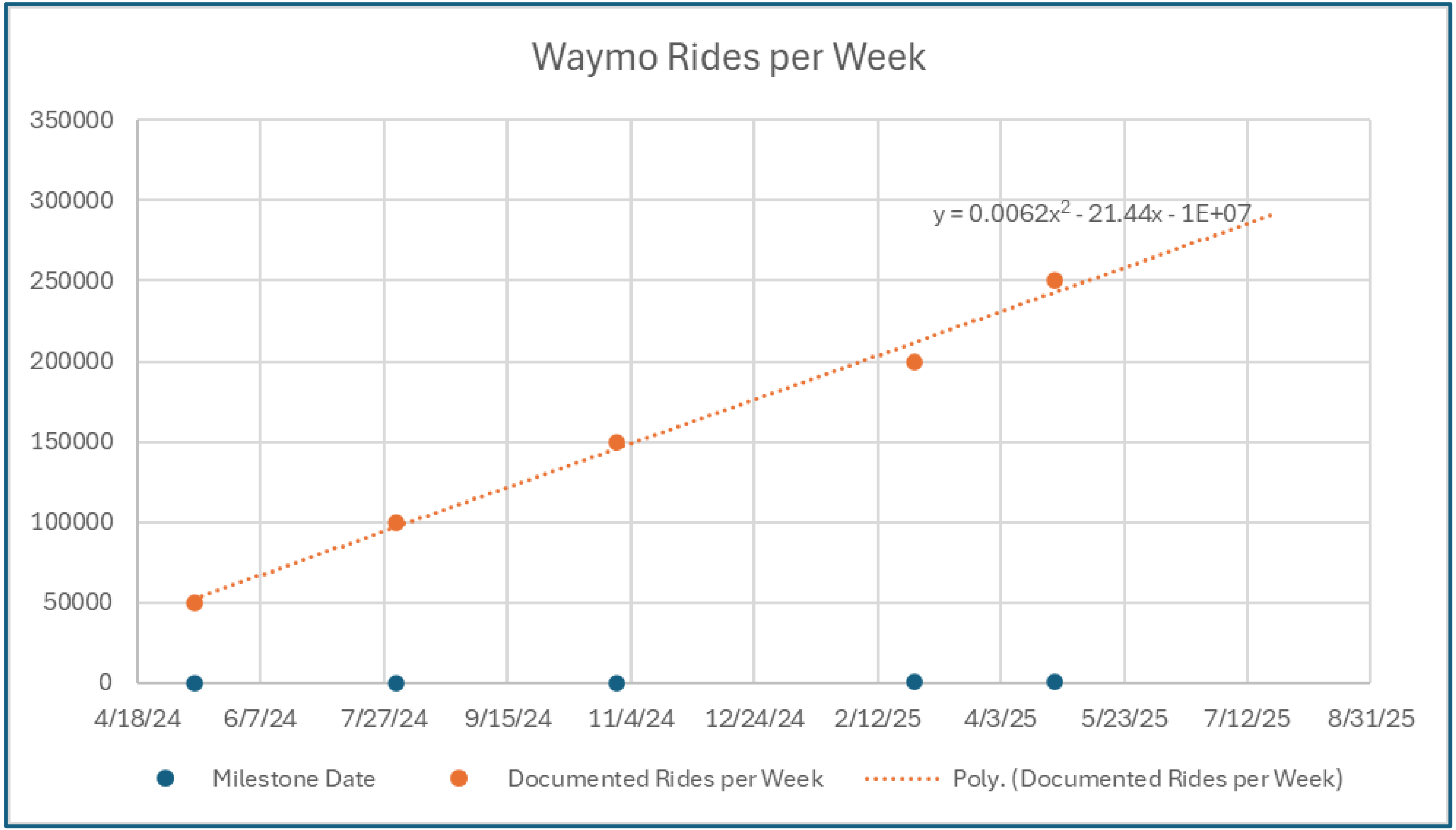
- **Passenger Transport**
  - **Waymo (Google)**
  - Zoox (Amazon), Tesla
  - Wayve, Pony AI
  - May Mobility, WeRide (Uber)
  - Perone Robotics
  - Oxa, Mobile Eye
  - MOIA (VW)
- **Freight Transport**
  - Aurora, Kodiak Robotics,
  - Gatik

Waymo Trips Milestones

- 50,000 paid trips per week – May 11, 2024
  - https://www.engadget.com/waymo-says-its-robotaxis-are-now-making-50000-paid-trips-every-week-130005096.html
- 100,000 Trips per week – August 2024
  - https://www.teslarati.com/waymo-100000-paid-rides-week/
- 150,000 Trips per week – Oct 29, 2024
  - https://seekingalpha.com/news/4221641-robotaxi-stunner-waymo-hits-milestone-of-15000-paid-autonomous-trips-a-week
- 200,000 Trips per week – Feb 27, 2025
  - https://techcrunch.com/2025/02/27/waymo-has-do
- **250,000 Trips per week – Apr 25, 2025**
  - https://www.cnbc.com/amp/2025/04/24/waymo-re
- Over 5 million total trips – Dec 18, 2024
  - https://waymo.com/blog/2024/12/year-in-review-20
  - https://www.youtube.com/watch?v=Z-ktqTBrkzU



Waymo Rides per Week – Updated 4/2025



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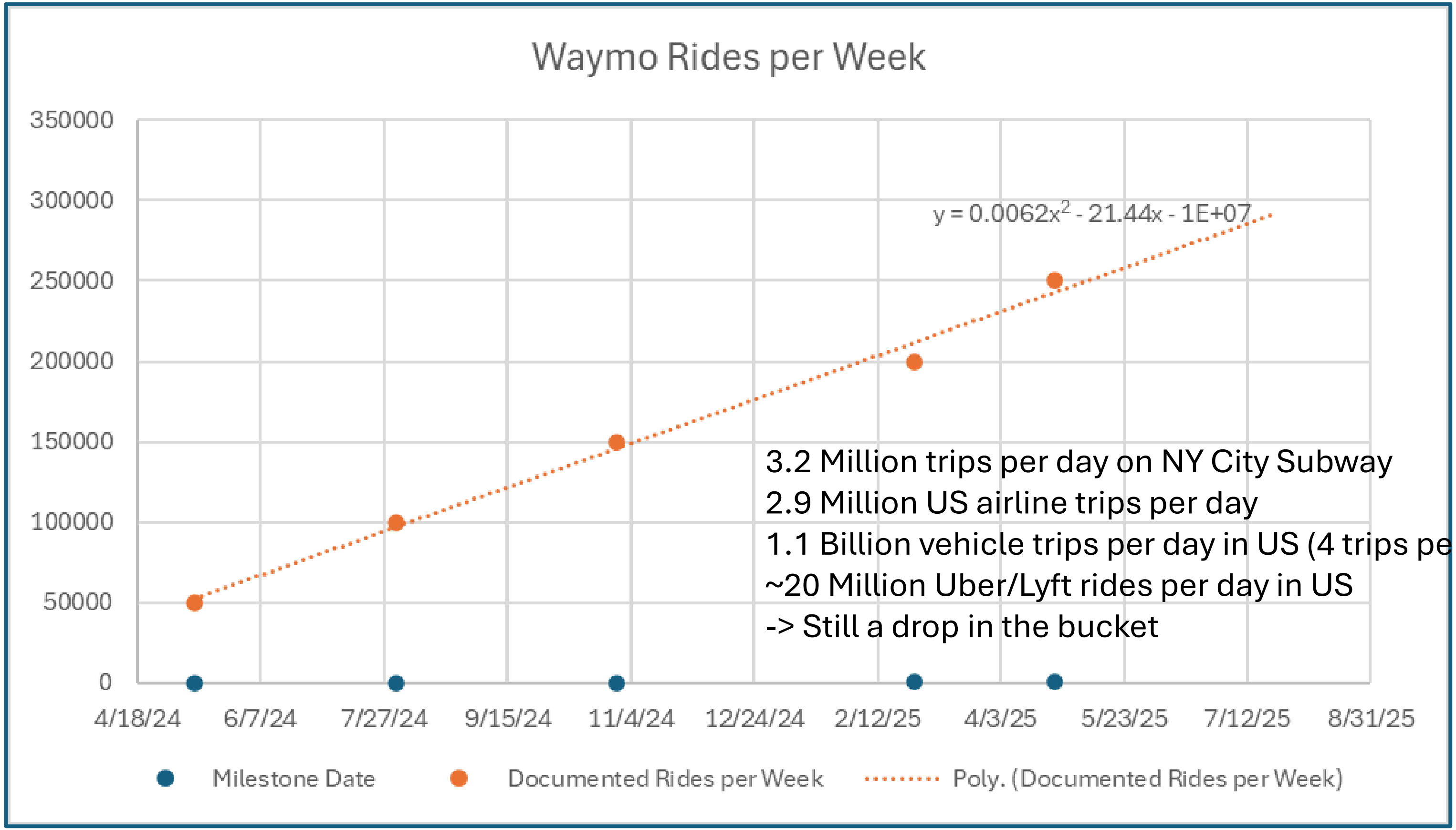


3.2 Million trips per day on NY City Subway
2.9 Million US airline trips per day
1.1 Billion vehicle trips per day in US (4 trips per person)
~20 Million Uber/Lyft rides per day in US
-> Still a drop in the bucket

Map of Waymo Deployments

Fully Operational Deployments Planned Deployments Testing

San Francisco, CA
Jun 2024 – Open to public

Los Angeles, CA
April 2024 – Paid service to all

Phoenix, AZ
Oct 2020 – began to pull safety drivers
Feb 2021 – Went fully driverless

Austin, TX
March 2025

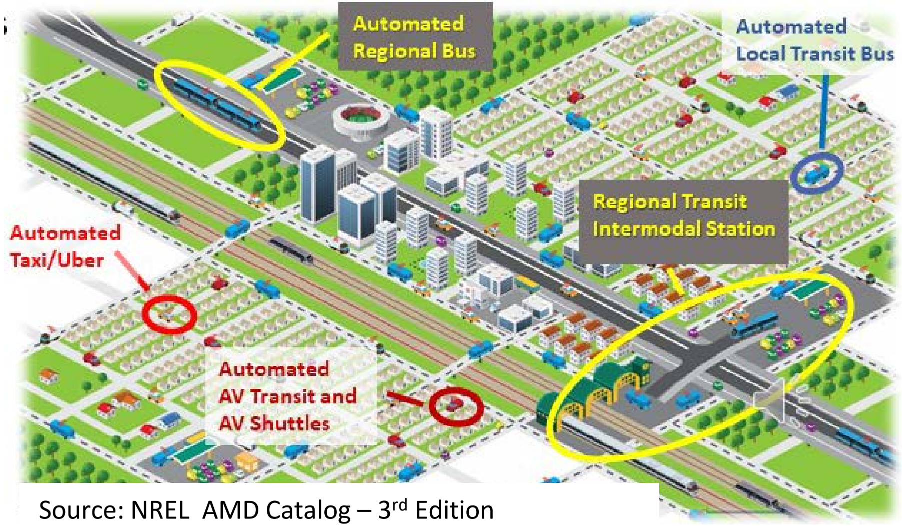
Washington, DC
2026

Atlanta, GA
2026

Miami, FL
2026

Benefits and Challenges of Automated Mobility (beyond the Automated Driving System)

1) Automated Fleet Management
2) Automated Charging
3) Customer Interface
4) Exception/Emergency Handling
5) Multi-party Ride Sharing



Source: NREL AMD Catalog – 3rd Edition

(1) Automated Fleet Management

Challenges in Automated Operations

- Passenger On-Demand Trip Request
- Fully Automated Vehicle Dispatch
- All aspects of a TNC service now operating in AV Fleets
- Industry Evidence of the Impacts of AV Fleet Operational Challenges
  - Waymo partnering with Uber

Three visible Waymo vehicles show extensive AV service in Downtown San Francisco

Image Credit: J. Sam Lott

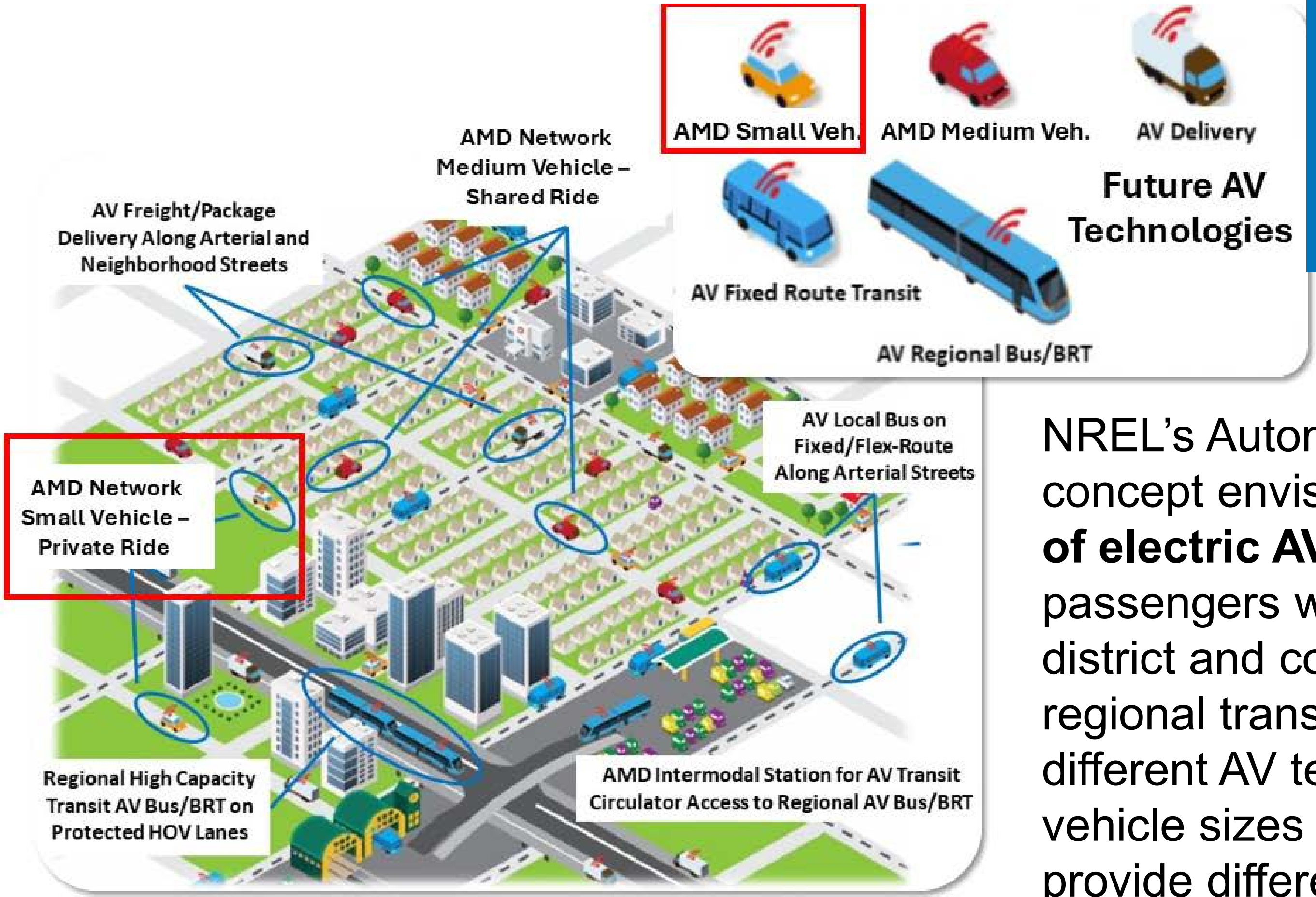
Automated Fleet Management

Following GM Board decision to cease the operations of Cruise AV, GM CEO Mary Barra was quoted as saying:

“Cruise was well on its way to a robotaxi business — but when you look at the fact you’re deploying a fleet, there’s a whole operations piece of doing that … ”

CNBC online publication, **GM exits robotaxi market, will bring Cruise operations in house,** December 10, 2024 – https://www.cnbc.com/2024/12/10/gm-halts-funding-of-robotaxi-development-by-cruise.html

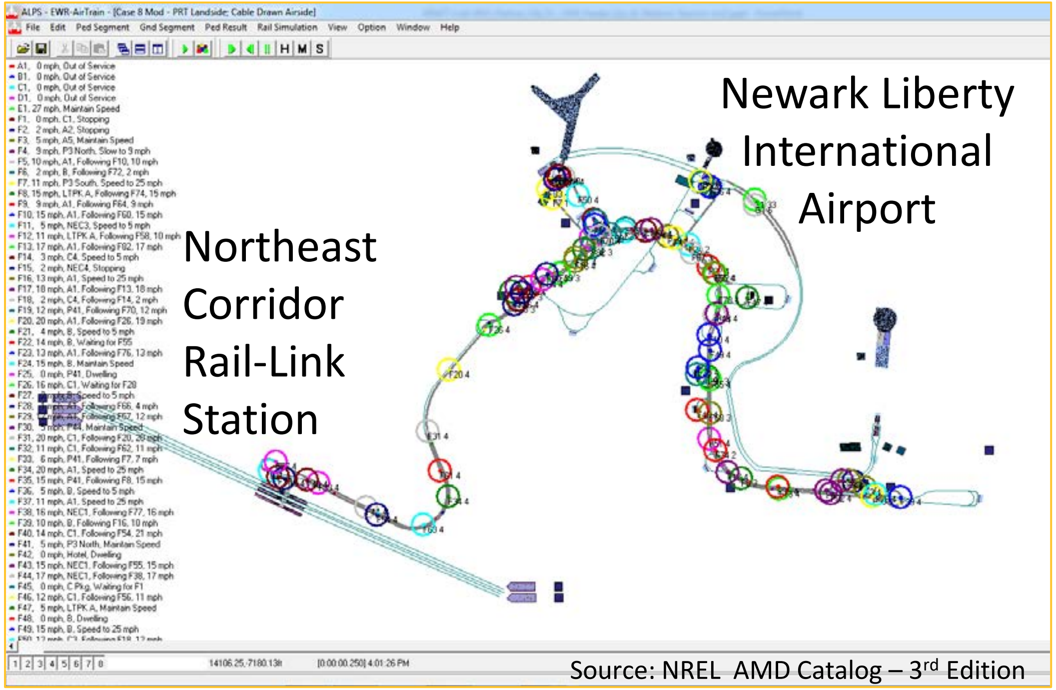
Automated Fleet Management



Source: NREL AMD Catalog – 3rd Edition

NREL's Automated Mobility District concept envisions **multiple fleets of electric AVs** circulating passengers within a dense urban district and connecting them to regional transit. The range of different AV technologies and vehicle sizes will be deployed to provide different service modes – **a System of Systems**.

Automated Fleet Management



Source: NREL AMD Catalog – 3rd Edition

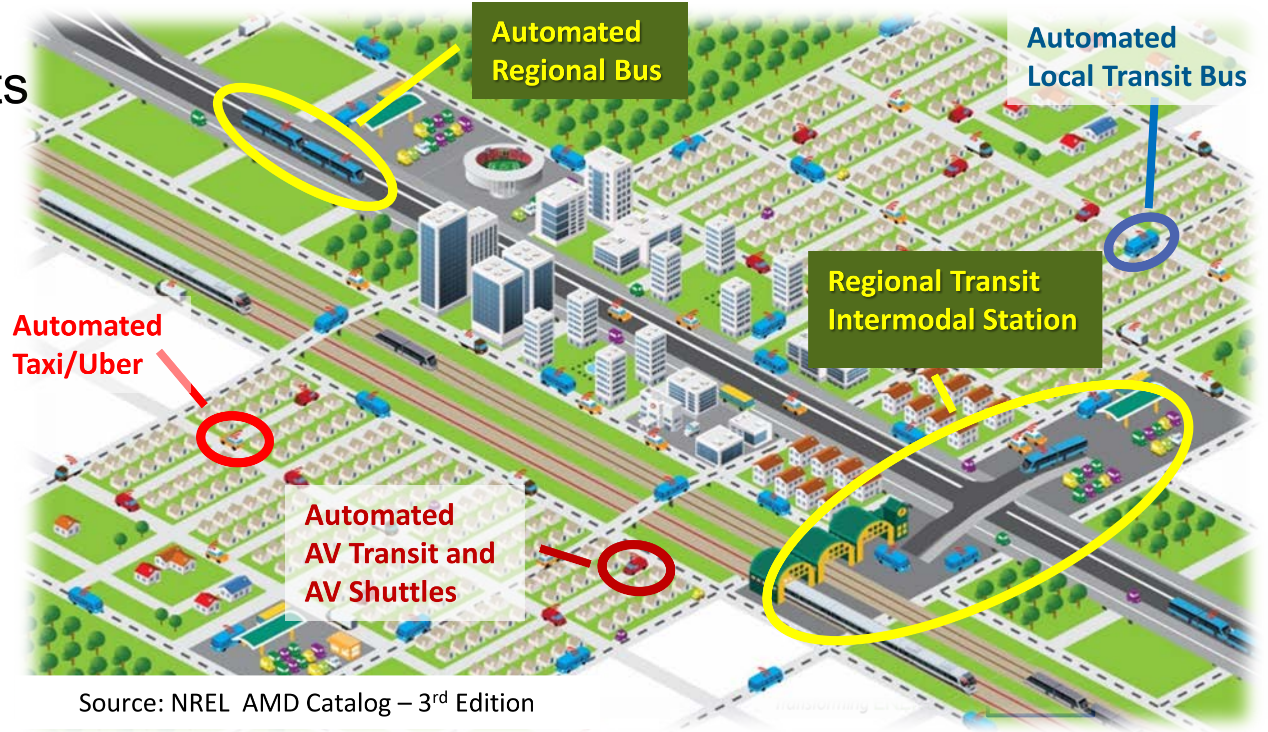
Challenges in Fleet Management

- Imbalanced demand within AV service network can dominate O/D trip patterns
- **Empty Vehicle Management** – e.g., strategic positioning of spare empty vehicles to carry ridership surge flows, such as at Regional Transit Intermodal Stations

Automated Fleet Management

High Demand Stations within the AV Fleet service area are typical for intermodal connections with regional transit

AMDs in Urban Districts and Major Activity Centers will have AV circulation and FM/LM connections to high-capacity AV systems at a regional transit Intermodal Station.



Source: NREL AMD Catalog – 3rd Edition

(2) Automated Charging of the Fleet

Challenges for Battery-Electric AV Fleets Involve Operational Impacts of Battery Recharging Frequency and Process

- Dedicated battery charging infrastructure rating and non-linear battery charging rates can create extended dwell times

<u>**Small Vehicle Charging Levels**</u>	**Charging Time (Hrs)****	**Power (kW)**
Level 1 Charging Station	12+	2.4
Level 2 Charging Station	6+	11.5
Level 3 Charging Station*	0.25-0.5	250

*DC Fast Charging Station

** Reference – Tesla Model X, 200 mile Range

Automated Charging of the Fleet

Hypothetical Example

Level 3 DC Fast Charging Infrastructure for Transit Fleets

- 16 charging positions - A/EVs operating in on-demand service.
- 4 DC power supplies (250 kW max power), each serving 4 positions
- Vehicles recharged in 15 to 45 minutes during fleet operations
- NREL estimate: $2.5M capital cost, no power grid changes (~1.5MW)


Image Credit: J. Sam Lott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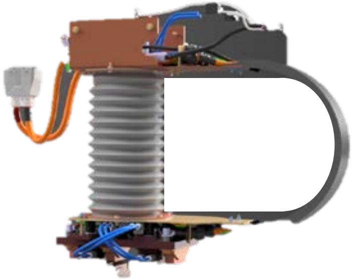
Automated Charging of the Fleet

Challenges for Battery-Electric AV Fleets

- Most charging remains manual plug-in charging stations (in US), which is counter productive for AV fleet operations
- Technology for inductive charging or battery swapping not prevalent, but is in active development
- Hard-Contact DC Charging Equipment as Installed on the ZF/2getthere vehicle** is designed to provide fully automated battery charging in stations and storage areas

** Oceaneering Intl. is the U.S. partner for ZF/2getthere ATN shuttle technology

Automated Charging of the Fleet



Source: NREL AMD Catalog – 3rd Edition

Challenges to Battery-Electric AV Operations

Challenges for Battery-Electric AV Fleets

- State of Charge (SOC) is an essential parameter needed in real time for vehicle dispatch and fleet management
- The Operational Battery Charging Strategy is necessary to develop during the fleet deployment initial planning
- Operational Changes to the Charging Strategy may be constrained by the Charging infrastructure once installed.

Challenges to Battery-Electric AV Operations

A site-specific battery charging strategy should be developed through a detailed design assessment of vehicle power consumption and the related vehicle operating speed and performance.

- Where will charging infrastructure be located?
- What type of charging (Level 2 or Level 3 Fast Charge) will be required to support the specific fleet operating plan?
- What will be the necessary electrical grid's power supply capacity and the site's spatial size and layout for each charging location?

The answers are much more complicated for On-Demand Service

(3) Customer Interface & Communications

Challenges in Customer Interface –

"Drivers typically handle adhoc, non-verbal and other customer communications beyond ride request."

- **Examples**
  - **Can you recommend a good restaurant?**
  - **Vehicle meeting the customer**
    - **Finding rider on a busy curb – eye contact**
    - **Finding rider on an empty curb – (not 50 yards past)**
  - **Deboarding – 'Do you have all your luggage?'**

Image Credit: S.E. Young

Tactics for Customer Interface & Communications

- **AI assistants – becoming increasingly common**
- **Exterior customer interface (Waymo - customer initials displayed on vehicle)**
- **Local positioning system to 'find rider on the curb' (does not exist yet)**
- **Monitoring cabin and trunk (boot) for any articles**
  - May be complex for multi-party rides
- **Extensive app capabilities ('I forgot my umbrella in the car')**
- **Rate the 'virtual driver' or service**

Image Credit: NREL 2023

(4) Exception/Emergency Protocol

Foreseeable Exceptions/Emergencies

- Vehicle Failure – (integral to fleet management)
- Vehicle Collision – (close coordination with EMS)
- In-Vehicle Emergency – i.e. heart attack
- Vehicle navigates outside of its Operations Design Domain
  - Flash floods (water on road), wet concrete, work zones
- Vandalism, and outside threats – ‘Coning of vehicles’

Unknown, unforeseeable exceptions, emergencies …

- Need general exception escalation and response – including local emergency response

(5) Multi-Party Ride Sharing

Multi-Party Ride Sharing with/without AVs

- **Human driver is neutral authority figure**
- **Commercial ride-hailing – ride sharing not compulsory (opt out)**
- **On-Demand Mobility (Micro-Transit) - ride sharing typically compulsory**
- **Social mixing can be uncomfortable – particularly with only two parties**
- **Historical precedence – WVU Personal Rapid Transit**
  - **Capable of direct origin to destination service**
  - **During off hours ran in fixed-route mode due specifically to personal security – provides opportunities to exit system at each stop**

Unattended Multi-Party Ride Sharing – The Horizon

Research – Human Proximity in Space and Time

- **Proxemics teaches us …**
  - 18” is personal space / boundary --- Family and friends - 18 inches to 4 feet
  - Casual and professional relationships is 4-10 feet --- Strangers >10 feet
- **Time**
  - **Elevator rides**
    - Typically 1 minute or less, and in a common building
- **Very little research or guidance**
- **Escape/control button or mechanism….**
  - General emergency services / 911 mechanism for inappropriate activity
  - Simple – ‘I’m uncomfortable – let me exit as soon as possible’

Tactics for Unattended Multi-Party Ride Sharing

- **Options for non-compulsory ride sharing (practical only for commercial services)**
- **Larger, roomier vehicles**
- **Partitions – separate seating areas within vehicles**
- **Social profiles for digital trust (unprecedented)**
- **Education – use of escape/control button/mechanism to end ride early**
- **Digital third-party presence or Virtual third-party presence**
- **Conspicuous monitoring (‘You are being watched’)**
- **Multiple party service (safety in a crowd)**
    - **Two parties may be uncomfortable, 3 or more provides ‘crowd safety’**

Q&A

www.nrel.gov

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