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U.S. DEPARTMENT OF ENERGY SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

MODELING AND SIMULATION OF AUTOMATED MOBILITY DISTRICTS

VENU GARIKAPATI
National Renewable Energy Laboratory

DOE Vehicle Technologies Office
2020 Vehicle Technologies Office Annual Merit Review

Project ID# eems009
Pillar(s): Urban Science

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
Argonne National Laboratory · Berkeley Lab · Idaho National Laboratory · NREL National Renewable Energy Laboratory · Oak Ridge National Laboratory

OVERVIEW

Timeline

- Project start date: 10/1/2016
- Project end date: 9/30/2019
- Percent complete: 100%

Budget

- Total project funding
  - DOE share: $720K
  - Contractor share: $0
- Funding for FY 2019: $250K

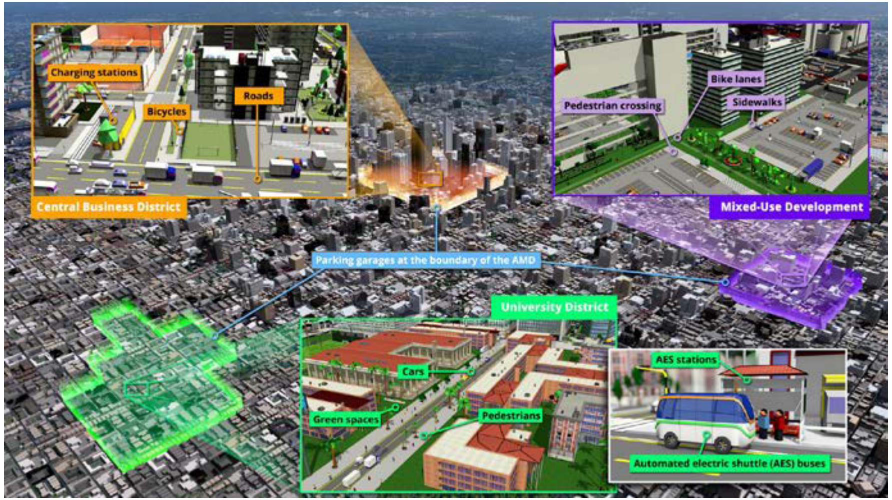
Barriers

- Design and simulation methodologies for automated mobility districts (AMDs)
- Computational models for connected/automated vehicles (CAVs)
- Lack of real-world data to support AMD modeling efforts.

Partners

- SMART Mobility Laboratory Consortium
  - National Renewable Energy Laboratory (NREL)
  - Oak Ridge National Laboratory (ORNL)
  - Idaho National Laboratory (INL)
- Greenville County, South Carolina
- University of South Carolina (sub)
- Automated Mobility Services, LLC (sub)

WHAT IS AN AUTOMATED MOBILITY DISTRICT?



An AMD is a campus-sized implementation of CAV technology to realize the full benefits of a fully electric automated mobility service within a confined region or district.

Connected, automated, and electric vehicles and **Mobility-as-a-Service (MaaS)**

Transportation planners rely on **travel demand simulation and models** to understand the mobility and energy impacts

In the short term, many cities are testing **low-speed automated electric shuttles** as a shared on-demand mobility service in **geo-fenced regions**

AMD

Existing models lack the capabilities to model emerging mobility technologies such as **on-demand shared mobility**

AMD simulation toolkit

RELEVANCE

Project Objectives

- **Quantify the net mobility gains and energy impacts** of automated, connected, electric, and/or shared (ACES) vehicles deployed in dense urban districts
- Develop modeling capabilities for VTO to estimate the energy and environmental effects of AMDs
- Integrate AMD model into existing regional travel models to simulate AMDs as a "special generator" in the region to quantify energy and mobility impacts
- **Directly aligned with EEMS strategic goal** to "develop new tools, techniques, and core capabilities to understand and identify the most important levers to improve the energy productivity of future integrated mobility systems."

Intra-District Impacts

- Mobility and energy of AMD fleet
- Land use changes.

Inter-Regional Impacts

- Modal choice
- Route choice
- Activity choice.

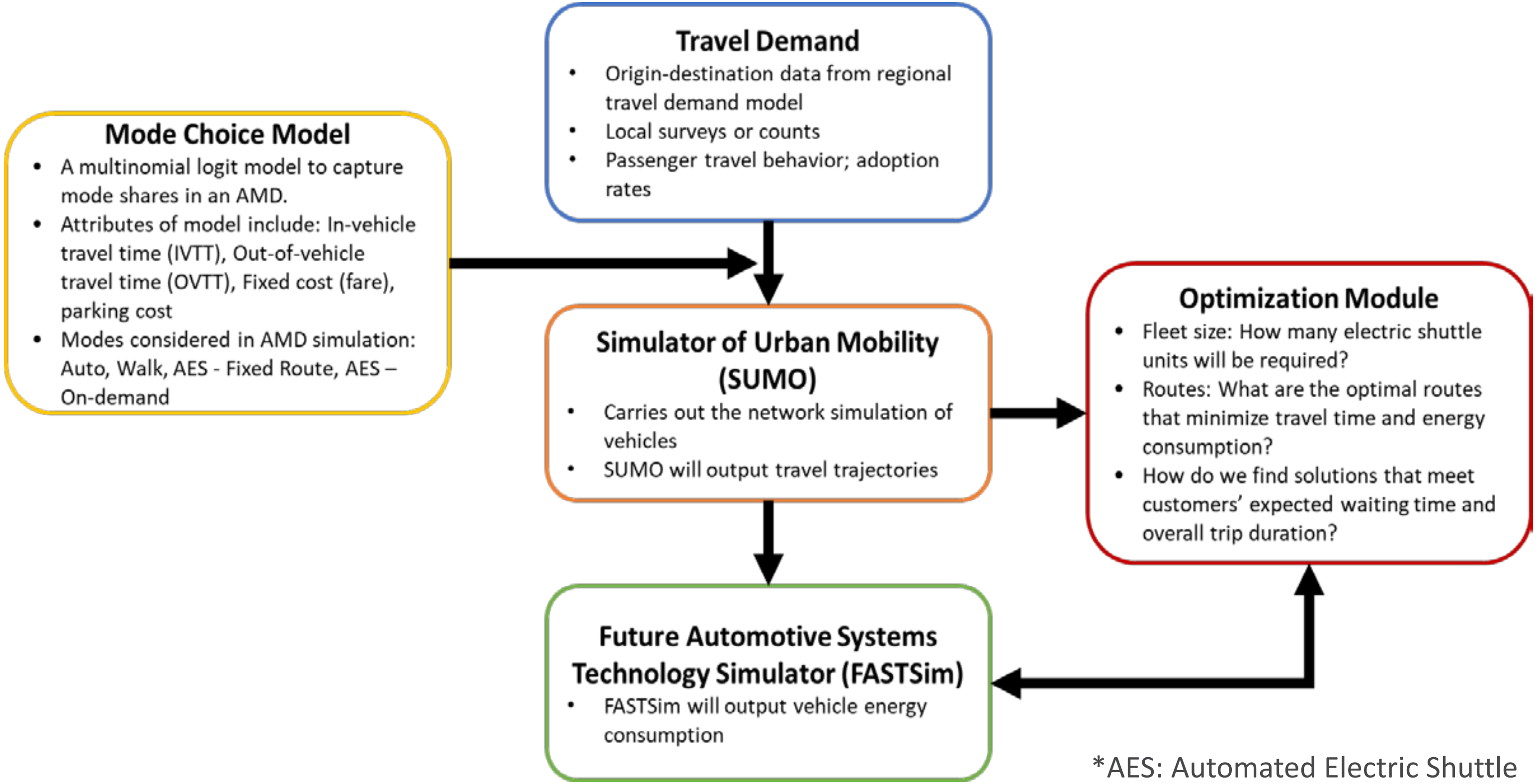
Boundary Issues/Effects

- Mode transfer/parking
- Boundary services
- Transportation Network Companies (TNCs), car sharing/rental.

MILESTONES

Month/Year	Description of Milestone or Go/No-Go Decision	Status
February 2019	Integration of optimization module into AMD toolkit	Complete
June 2019	Integration of mode-choice model into AMD toolkit	Complete
August 2019	Presentation on the comprehensive AMD deployment assessment tool that integrates AMD microsimulation Simulation of Urban MObility (SUMO), fleet optimization, and energy estimation	Complete
September 2019	Conduct AMD simulation in at least one location in addition to Greenville	Complete
December 2019	Automated Mobility District Implementation Catalog – Insights from Early-Stage Deployments	Underway

APPROACH: AMD SIMULATION TOOLKIT – MODEL FLOW



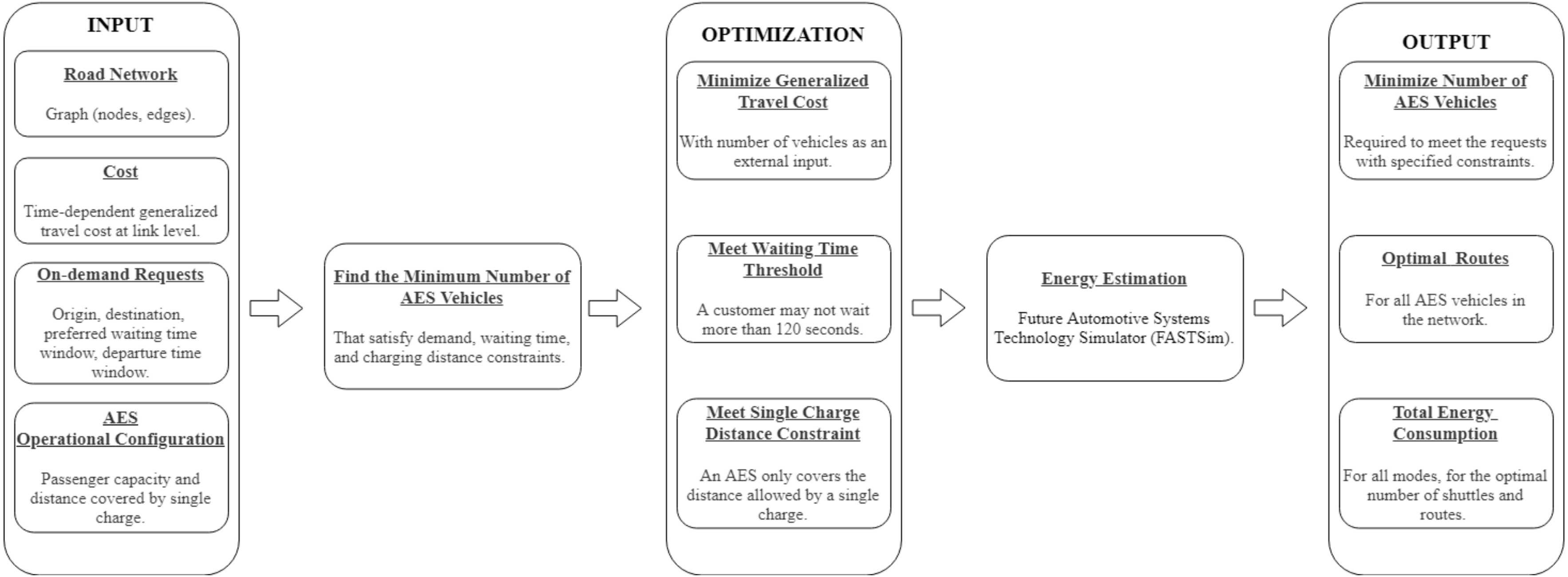
*AES: Automated Electric Shuttle

APPROACH: TASKS

Plan for FY 2019

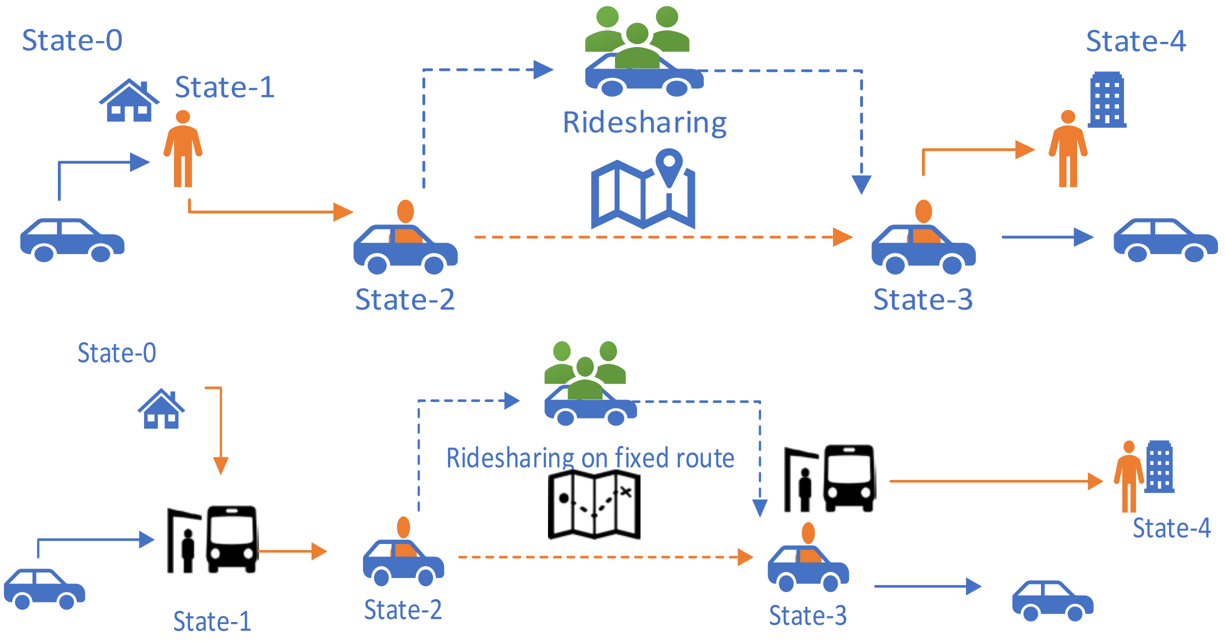
- **Fleet and Route Optimization Module**
  - To determine the optimal configuration (number and capacity) of shuttles and optimal routes to serve a given demand
- **Mode-Choice Model**
  - Develop a mode-choice model that is responsive to shuttle operations (frequency, capacity) and regional transportation infrastructure
- **Application of AMD Toolkit**
  - Exercise the AMD toolkit in at least one additional deployment location to Greenville, South Carolina
- **Gain insights from early-stage AMD deployments**

APPROACH: OPTIMIZATION MODULE



APPROACH: AMD SUMO SIMULATION

Door-to-Door (DTD) and Fixed-Route Ride (FXR) Sharing

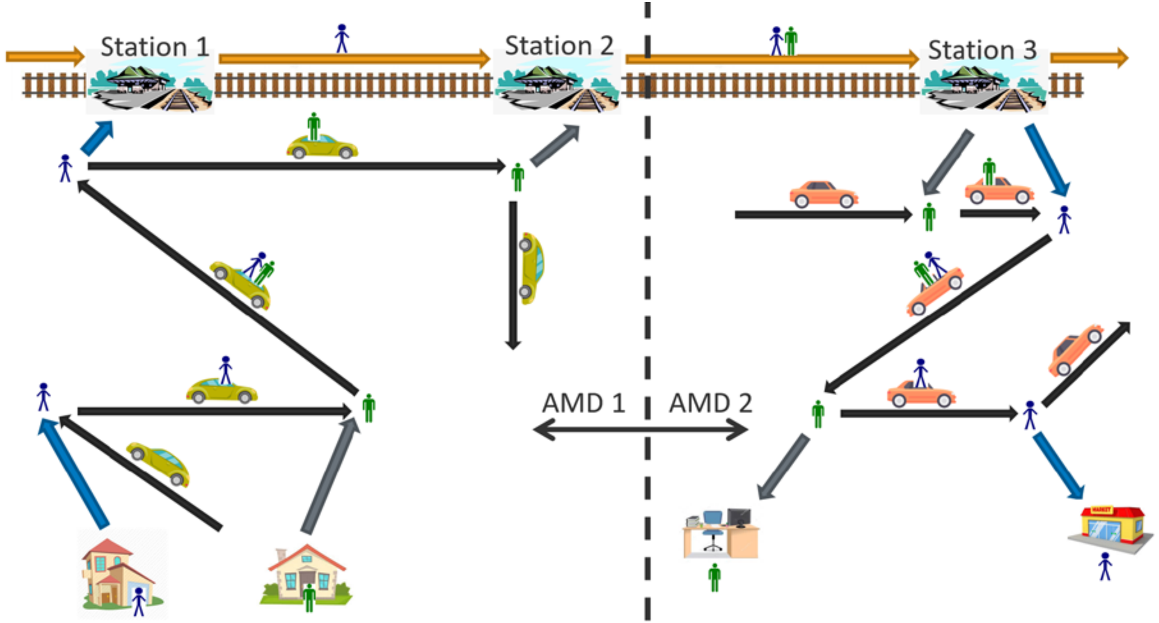


Passenger states

0 - Initialization
1 - Arrive at pickup location and wait
2 - Get on board
3 - Arrive at drop-off location and alight
4 - Arrive at destination and stop

APPROACH: FMLM CONNECTIONS TO TRANSIT

Shared, Automated Vehicles (SAVs) as First-/Last-Mile (FMLM) Connections



Real-Time Simulation and Control

- Controller can obtain and react to a rider's current status and location
- Every 5 minutes (**300 s**), SAV ride requests are evaluated and **vehicle routing plans** are generated
- SAVs can provide FMLM service in **one** routing plan.

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

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FY 2019 (Previous Accomplishments)

- Preliminary AMD simulations using Greenville data
- Development of AMD operational configuration optimization module
- Initiation of mode-choice module development.

FY 2019 Accomplishments (Post-AMR 2019)

- Enhanced the optimization module; developed a graphical user interface
- Implemented the mode-choice module post-AMR
- Carried out AMD simulations in Austin, with SAVs serving as first-/last-mile connections to transit
- Automated shuttle rider survey initiated at NREL.

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

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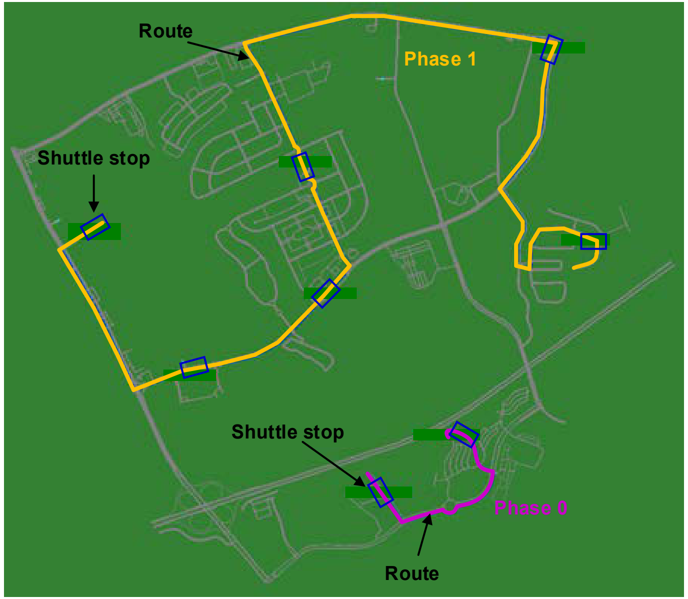
Automated Mobility District Implementation Catalog – Insights from Ten Early-Stage Deployments

AMD #	Site/Owner	Technology Supplier	Operator	Vehicle Model	Route Config. (Loop / Bi-directional)	Vehicle Capacity	Max. Operating Speed (mph)	Passenger Communications
AMD #1	Columbus, Ohio Drive Ohio (under Ohio DOT)	May Mobility	May Mobility	Polaris GEM	Loop	6	23	Onboard attendant
AMD #2	Arlington, Texas City of Arlington	EasyMile	First Transit	EZ10 Gen1	Bi-directional	12	12	Onboard attendant
AMD #3	Las Vegas, Nevada City of Las Vegas	Navya	Keolis	Autonom Shuttle	Bi-directional	15	16	Onboard attendant

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: GREENVILLE CASE STUDY

Testing the utility of the optimization module

- Morning peak hour (6–9 a.m.)
  - A total of 378 trips
- The time-dependent demand distribution: Total 308 trips
- Four modes:
  - CAR: regular car
  - WAK: pedestrian
  - SAV modes:
    - — DTD: on-demand door-to-door ridesharing
    - — FXR: on-demand fixed-route ridesharing
- SAV configuration:
  - SAV capacity: four passengers
  - 10 SAVs: 6 for FXR mode and 4 for DTD



Network in SUMO and two fixed routes

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: GREENVILLE CASE STUDY

Scenario Study and Analysis

Baseline

- Scenario 0: with CAR and WAK modes only

DTD mode only

- Scenarios 1–3: 10% increments shifting from CAR mode

FXR mode only

- Scenarios 4–6: 10% increments shifting from CAR mode

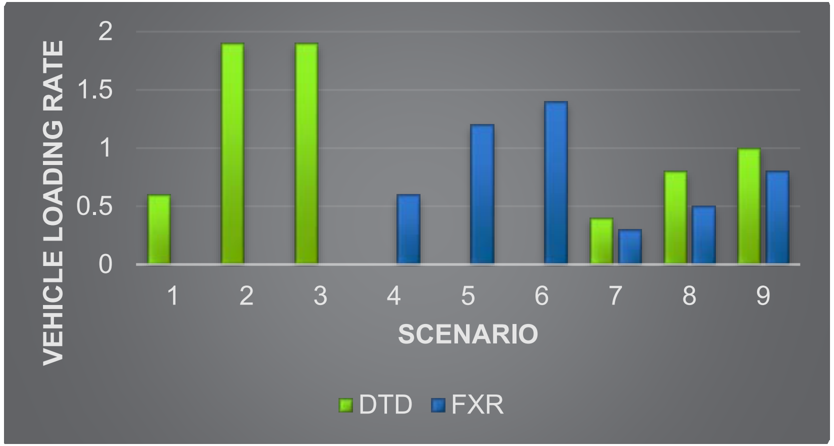
DTD and FXR modes

- Scenarios 7–9: 10% increments (5% of DTD, 5% of FXR)

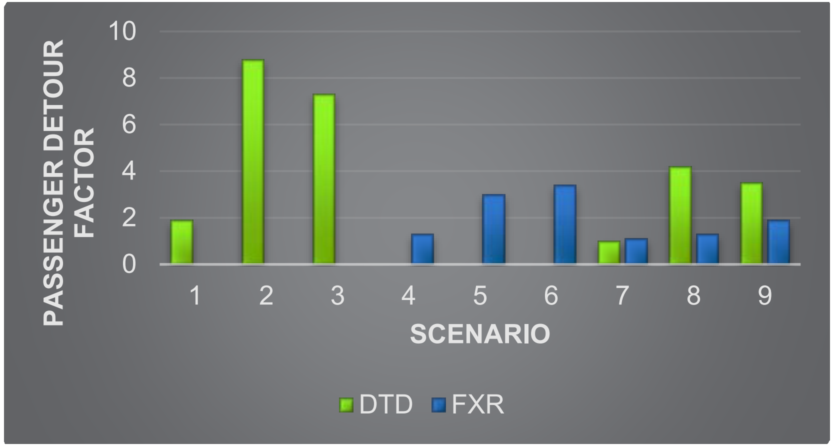
	Mode Share Ratio			
Scenario ID	**CAR**	**WAK**	**DTD**	**FXR**
0	0.8	0.2	0	0
1	0.7	0.2	0.1	0
2	0.6	0.2	0.2	0
3	0.5	0.2	0.3	0
4	0.7	0.2	0	0.1
5	0.6	0.2	0	0.2
6	0.5	0.2	0	0.3
7	0.7	0.2	0.05	0.05
8	0.6	0.2	0.1	0.1
9	0.5	0.2	0.15	0.15

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: GREENVILLE CASE STUDY

SAV Service Performance Metrics



Passenger detour factor: trip distance of ridesharing modes divided by trip distance of regular car mode (time-dependent shortest path).

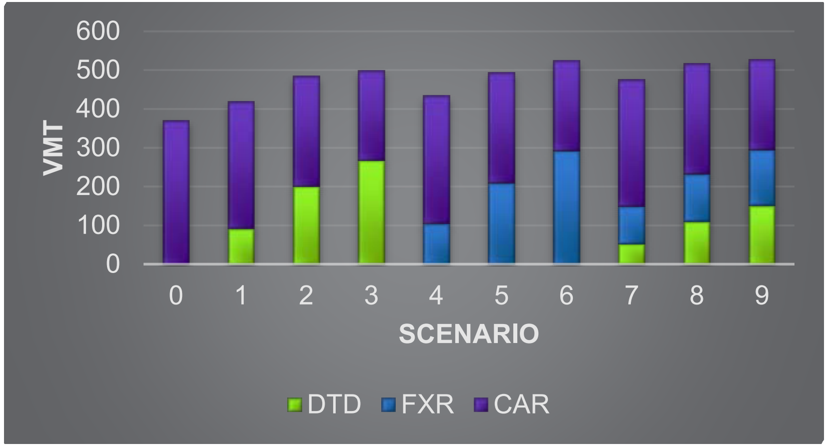


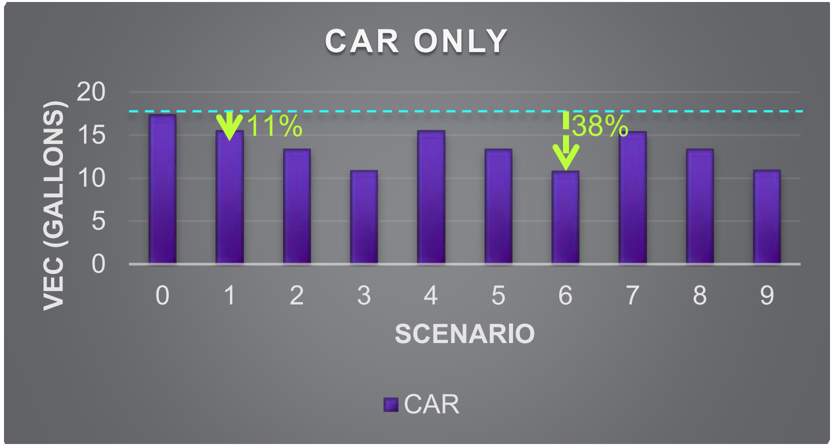
Vehicle loading rate (VLR):

- Distance-weighted number of passengers on board divided by the vehicle distance traveled for all SAVs
- For specific AMD configuration, DTD outperforms FXR mode with higher VLR

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: GREENVILLE CASE STUDY

SAV Service Performance Metrics





Vehicle miles traveled (VMT): SAV VMT increases as number of SAVs increases

- When both modes are deployed, there are more SAVs operating in the system, leading to higher system-level VMT.

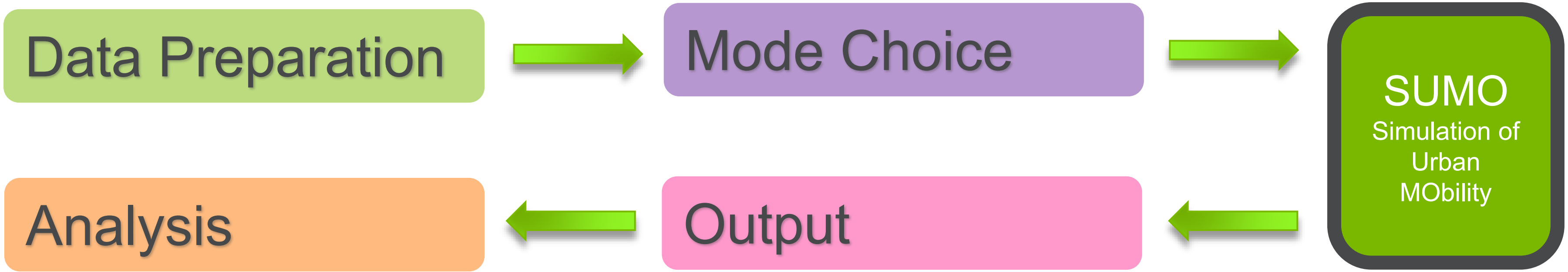
Vehicle energy consumption (VEC): In fuel (gallons)

- Scenario 0 has VEC of 17.4 gallons for CAR mode only
- If all SAVs are electric vehicles, the fuel saving ranges from 11% to 38%.

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: AUSTIN CASE STUDY

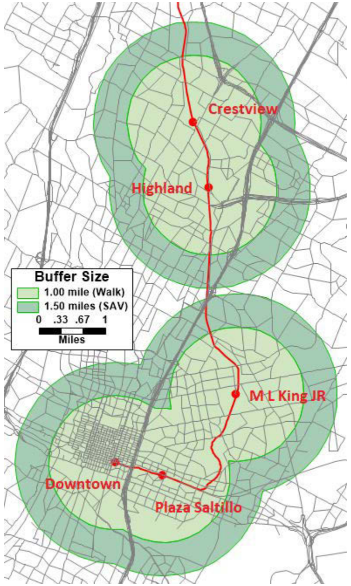
Framework

- Aim is to **quantify impact** of deploying SAVs as FMLM connections to transit in geofenced regions.
- **SUMO** (Simulation of Urban MObility) is used to simulate SAV fleets serving **multiple AMDs** along **a rail-transit line**.



TECHNICAL ACCOMPLISHMENTS AND PROGRESS: AUSTIN CASE STUDY

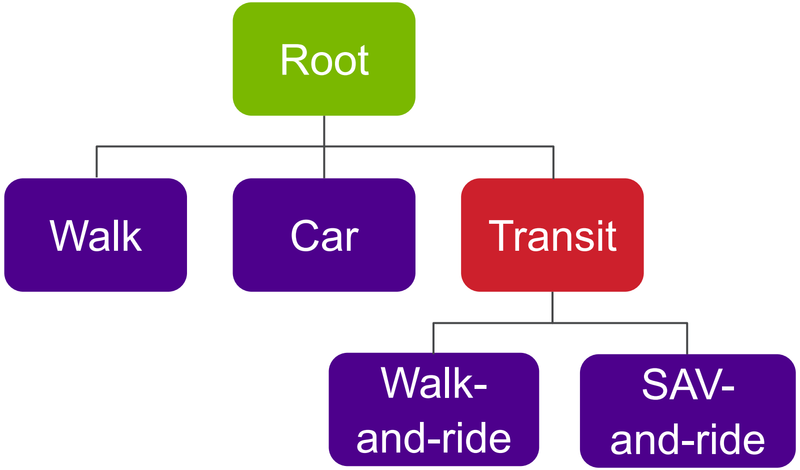
Network & Travel Demand



- Capital-Area Metropolitan Planning Organization (**CAMPO**) regional travel demand model (**year 2030 forecast**)
- **246 zones** extracted from 2,252 Traffic Analysis Zones (TAZs) covering Austin's six-county region
- 42,125 trips generated across the 246 TAZ sub-region from **6 a.m. to 9 a.m.**
- Simulate **1,019 person-trips = 2.5% sample** of morning peak trips.

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: AUSTIN CASE STUDY

Mode Choice



Model specifications adapted from: Liu et al. 2017; Wen et al. 2018; Chen and Kockelman 2016.

Critical Parameters and Assumptions

Transit (Train) Mode

- Flat Fare of **$2 per transit ride**
- Speed = **32 mph**

Walk-and-Ride

- Available when access and egress distance **<1 mile**
- Access and egress walking time at **3.2 mph**

SAV-and-Ride

- Available when access and egress distance **<1.5 miles** (AMD radius)
- Operating Cost = **$1/mile**
- Access or egress mode wait time + driving time and distance + some walking time

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: AUSTIN CASE STUDY

With and Without SAVs as FMLM Connections

- Transit frequency = 15 min
- SAV operating cost = $1/mile
- SAVs in each AMD = 15
- 2.5% morning peak sample

	Mode Share				Vehicle Miles Traveled			
	Car	SAV & Ride	Walk & Ride	Walk	Car	SAV Occ.	Empty	Total VMT
Base	70.8%	0%	0.79%	28.3%	2,827	0	0	2,827
	721 trips	0	8	289				
FMLM	55.0%	16.6%	0.79%	27.6%	2,162	1,516	851	3,554
	560 trips	169	8	281				

*Preliminary Results

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

Only questions that need a response are included here. Additional reviewer comments are noted in the Reviewer-Only Slides.

- Q1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well designed and well planned.
  - Reviewers commented that the city "demonstrations" (and real-world data) are critical to gaining acceptance of the model for use by municipalities in conducting their planning. Sans these demonstrations, the reviewer asserted that the project should seek other methods to gain user confidence in the modeling.
  - The reviewer makes a valid point. As a part of this year's project activities, we have developed an AMD catalogue that summarizes the state of operations of ten early-stage AMD deployments across the United States. While many of these deployments are active, none have a significant ridership yet. So, the project team is exploring two other avenues to advance the state of data and modeling activities: (1) through NREL, we are planning to deploy a six-question survey to users of the automated shuttle on campus; (2) we tested the transferability of the AMD toolkit to an additional deployment location (Austin) to demonstrate the ease of adopting the AMD toolkit for a specific deployment context.

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

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Only questions that need a response are included here. Additional reviewer comments are noted in the Reviewer-Only Slides.

- Q2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.
  - The reviewer said that the mode-choice model cannot be properly calibrated due to the lack of data. It is understandable that a revealed preference survey could not be done yet, but at least a stated preference survey could have been attempted. Without a proper mode-choice model, the reviewer commented that the AMD toolkit would not be very useful.
  - We fully agree with the reviewer's comment. Obtaining data from users who have used/experienced automated vehicle technology is key for good calibration of the mode-choice model. As noted above, none of the existing AMD deployments have sufficient ridership to obtain a good survey sample for calibration. We are hoping that the NREL Automated Shuttle Survey will gives us a first peek into SAV rider characteristics.

- Q3: Collaboration and Coordination Across Project Team
  - Why is the University of South Carolina a subcontractor for energy consumption modeling, which is the core expertise of NREL? Instead, the university would have been a perfect partner for doing the stated preference survey of local residents, according to the reviewer.
  - Our apologies for the confusion. University of South Carolina (USC) was subcontracted to help with energy consumption modeling but not lead it. An NREL researcher (who was working on AMD energy consumption modeling) recently moved to USC as an Assistant Professor. So, collaboration seemed natural and beneficial because we were using Greenville, South Carolina as our AMD deployment case study. As the reviewer suggested, in the future, we will use the collaboration with USC for survey of local residents.

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation

Only questions that need a response are included here. Additional reviewer comments are noted in the Reviewer-Only Slides.

- Q4: Proposed Future Research
  - The reviewer commented that substitute work to gain model acceptance with users is necessary to replace the AMD demonstrations that will not be completed.
  - Answered as a part of Q1 from the same reviewer.
- Q6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?
  - If the main reason for not pursuing more data collection to validate the AMD model is due to limited funding, then the reviewer indicated that the resources for the current project are insufficient.
  - The reviewer commented that the project team should be allocated more funding to collect more real-world data.
  - As noted by the project team, the reviewer stated that resources will not be sufficient to complete the AMD demonstrations originally planned.
  - We are grateful for this comment from the reviewers recognizing that current funding is not sufficient to accomplish everything planned for the project (particularly the real-world data collection). While we had the best of intentions in tackling various aspects of this new form of mobility, the pace of real-world deployments is something we clearly overestimated. That said, we believe that data collection for model development and calibration is still critical to the success of the project. We are exploring additional avenues (such as the NREL survey) to obtain data on rider characteristics. We have done preliminary analysis in adopting the toolkit in the context of using SAVs as FMLM connections in Austin, and would like to refine that analysis, if additional funds are available.

Any proposed future work is subject to change based on funding levels.

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

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- **Within VTO**
  - SMART Mobility Consortium Laboratories: NREL, ORNL, and INL
  - SMART Mobility Pillars: Advanced Fueling Infrastructure, CAVs, Mobility and Decision Science
- **Outside VTO**

Collaborators	Type	Extent
Greenville	County/City	AMD deployment partner, providing travel-demand and network-supply data
University of South Carolina	University	Energy consumption modeling support
University of Houston	University	Potential AMD deployment partners
University of Texas at Austin	University	Collaborating on FMLM researchers
Mineta Transportation Institute	Nonprofit	Coordinating on integrating AMD toolkit with BEAM (Behavior, Energy, Autonomy, and Mobility) model

REMAINING CHALLENGES AND BARRIERS

- **Integration of AMD toolkit** with regional Travel Demand Models (TDMs) for assessing inter-regional impact of SAVs
  - This was tagged as a project goal that will be accomplished if time and resources are available
  - Progress has been made in using data from TDMs to model AMDs
  - Full integration (feedback from AMD toolkit to TDM) will be explored in future research.
- **Data availability from real-world deployments**
  - Existing deployment is small-scale demos, rather than strategic long-term service offerings
  - Resource constraints to deploy user surveys in multiple early-stage AMD deployments.

Any proposed future work is subject to change based on funding levels.

PROPOSED FUTURE RESEARCH

- Incorporation of additional "**mobility-on-demand**" modes
  - Shared bikes, e-scooters, SAVs for first-/last-mile connections

- Integrating the toolkit into a **regional travel demand model**
  - Austin's regional travel model in the context of FMLM simulations

- FMLM Simulations
  - Enhancing operational logic with features like **dynamic ridesharing and deadhead minimization**
  - Rising demand levels and system size.

Any proposed future work is subject to change based on funding levels.

SUMMARY

- **Objective**: To develop modeling capabilities for VTO to estimate energy, emission, and mobility impacts of AMDs
- **FY 2019 efforts (presented at AMR 2019)** have focused on developing an optimization module that can inform operational configuration of automated shuttles in an AMD
- **Efforts post-AMR 2019**:
  - Incorporation of a mode-choice model that is responsive to operational characteristics of automated shuttles in an AMD
  - Replicating the AMD modeling process in one location in addition to Greenville
  - Initial steps toward integrating the toolkit into a regional travel demand model
  - Enhancement of the AMD fleet and route optimization module
  - Development of the AMD catalogue documenting insights from ten early-stage AMD deployments.

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TECHNICAL BACK-UP SLIDES

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: GREENVILLE CASE STUDY

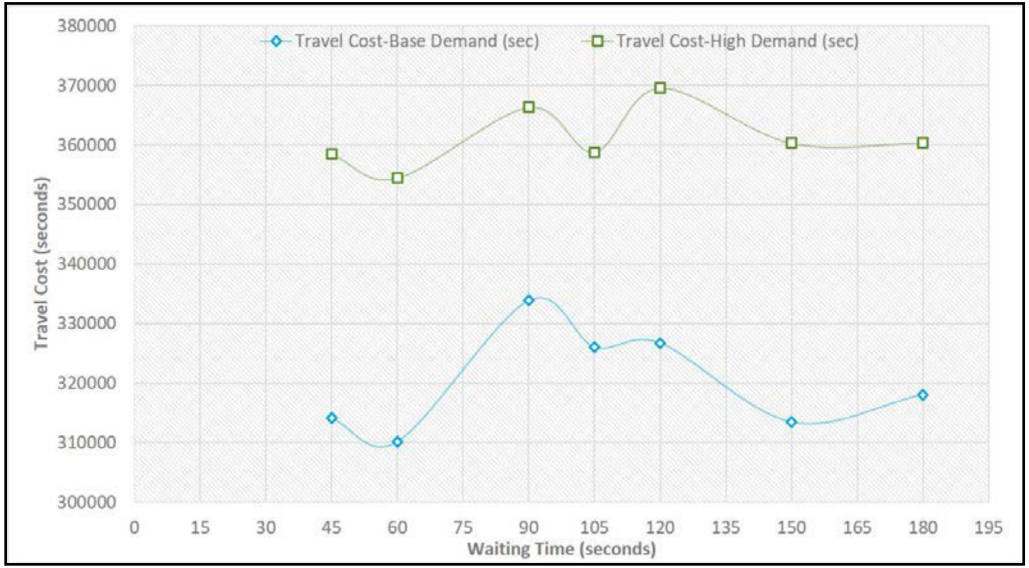
Testing the utility of the optimization module

- Morning peak hour (6–9 a.m.)
  - A total of 378 trips
- Overall mode shares for the experimental analysis are assumed as
  - FXR mode (20%)
  - DTD mode (30%)
  - Walk (10%)
  - Regular car (40%).
- Vehicle design parameters for AES are based on EasyMile EZ10 shuttle 14
- Shuttle capacity: {2, 4, 8}
- AES range: {20 km, 30 km, and 50 km}

Greenville, South Carolina network has 554 nodes, 1,340 edges, and eight TAZs

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: GREENVILLE CASE STUDY

Testing the utility of the optimization module



- More flexibility (**higher waiting time threshold**) may lead to **better system cost** (as in the case for moving to 60 seconds from 45 seconds)
- However, **adding further waiting time allowance can suppress the benefits**
- In other words, for a specified demand pattern and fixed-size fleet, waiting time threshold follows a nonlinear pattern