Optimizing Fleet Operations in Automated Mobility Districts

Serving On-Demand Mobility with Automated Electric Shuttles

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Joint work conducted by ORNL, NREL, University of Tennessee-Knoxville, and University of South Carolina

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Background

On-demand transportation services have seen a dramatic rise in the past decade, thanks to technology.

Connected and automated vehicle (CAV) technology holds potential for a major transformation in the on-demand mobility services landscape.

The timeline for fully automated vehicles (AVs) to reach the critical market share is still uncertain.

In the short term, many cities in the United States and abroad are testing low-speed automated electric shuttles (AES) as a shared on-demand mobility service in geo-fenced regions.

↓

Automated Mobility District (AMD)

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.

Real-World AMD Demonstrations

Find out when driverless vehicles will be hitting the streets of this North Texas city

BY BILL HANNA

JUNE 13, 2018 06:00 AM, UPDATED JUNE 13, 2018 12:57 PM

Arlington's new driverless shuttle is ready to serve the entertainment district

DEEP DIVE

How autonomous shuttles are changing city transportation

TREND

FOOD & LIFES

BrewDog

to new rol

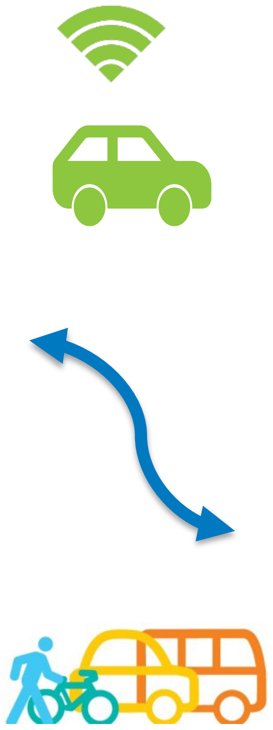
means

Current	Upcoming
Denver, CO	New York City, NY
Houston, TX	Rhode Island
Arlington, TX	Austin, TX
Las Vegas, NV	Reston, VA
Jacksonville, FL	Battle Creek, MD
Columbus, OH	Columbus – Linden, OH
Ann Arbor, MI	Sacramento State University, CA
Bishop Ranch, CA	Dublin, CA
Gainesville, FL	Rivium Park, Netherlands
Babcock Ranch, FL	

Automated Mobility Districts

Characteristics

- Fully automated and driverless cars
- Service constrained to an area with high trip demand
- Mix of on-demand and fixed route services
- Multi-modal access within/at the perimeter



Operational Challenges

- Customer demand (adoption rate)
- Fleet size
- Operational configuration:

  Fixed route vs. on-demand
- Battery capacity
- Mobility/energy impacts

Current State of AMD Modeling

Where We Are

Existing tools primarily emphasize:

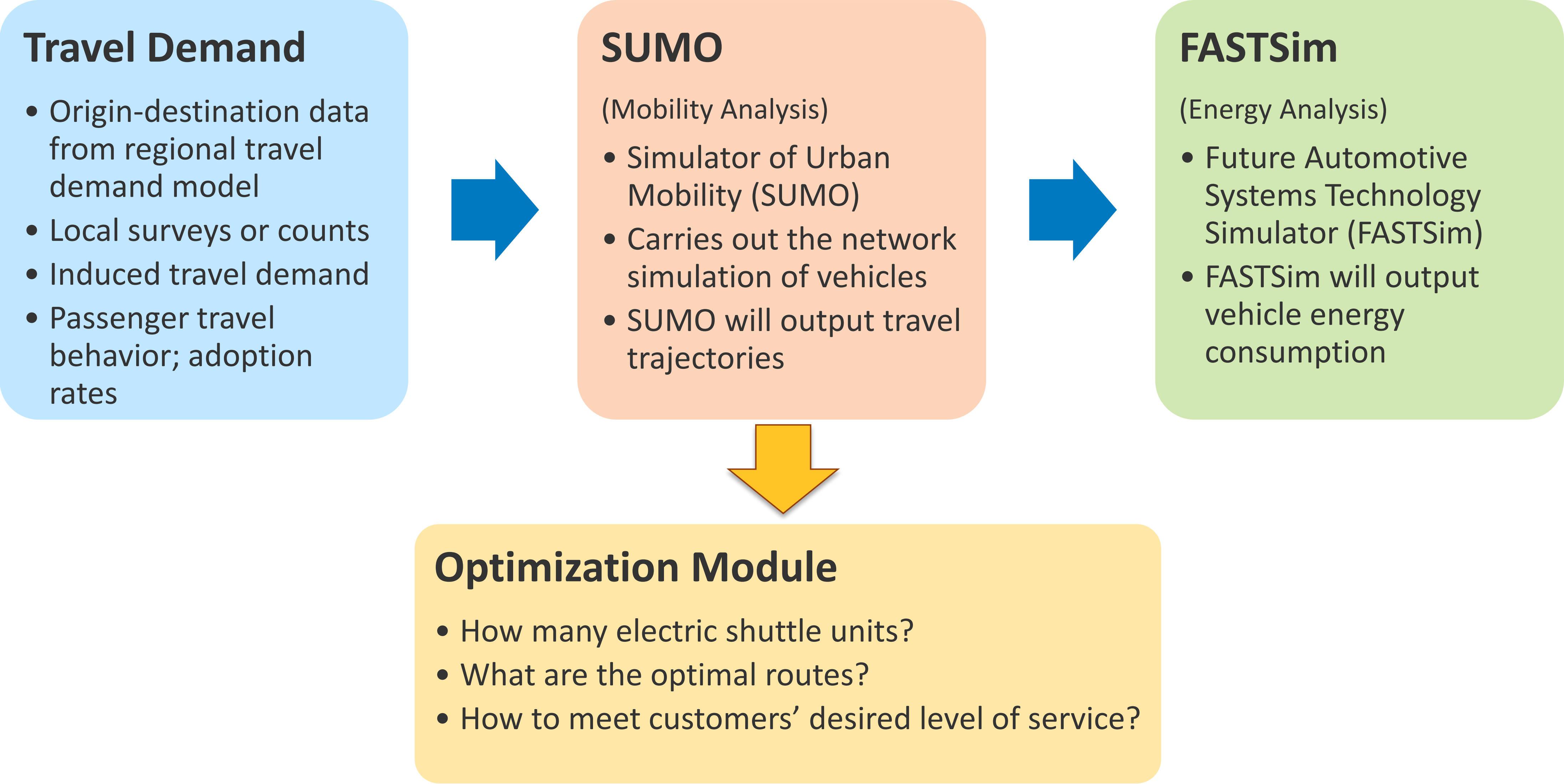
- The road network, with minimal to no consideration for pedestrian/bike/transit
- Privately owned vehicles, but do not model shared economies
- Solutions not customized to guide early-stage deployments

Where We Want To Be

Need modeling tools that:

- Capture private as well as shared economies in vehicles
- Are built from field deployments of emerging transportation technology
- Can quantify energy & emissions as well as mobility benefits

AMD Simulation Toolkit: Model Flow



Travel Demand

- Origin-destination data from regional travel demand model
- Local surveys or counts
- Induced travel demand
- Passenger travel behavior; adoption rates

SUMO

(Mobility Analysis)

- Simulator of Urban Mobility (SUMO)
- Carries out the network simulation of vehicles
- SUMO will output travel trajectories

FASTSim

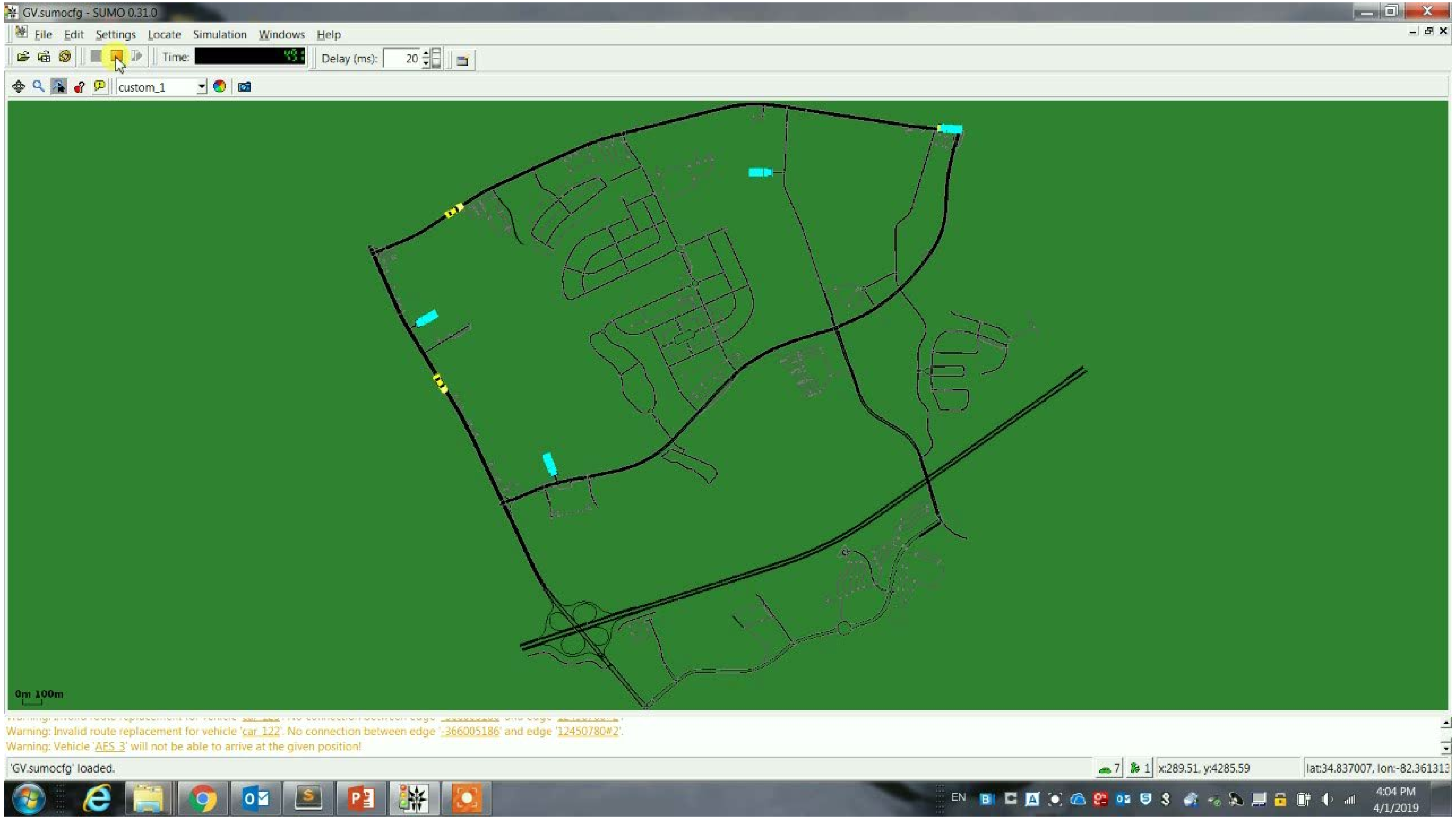
(Energy Analysis)

- Future Automotive Systems Technology Simulator (FASTSim)
- FASTSim will output vehicle energy consumption

Optimization Module

- How many electric shuttle units?
- What are the optimal routes?
- How to meet customers’ desired level of service?

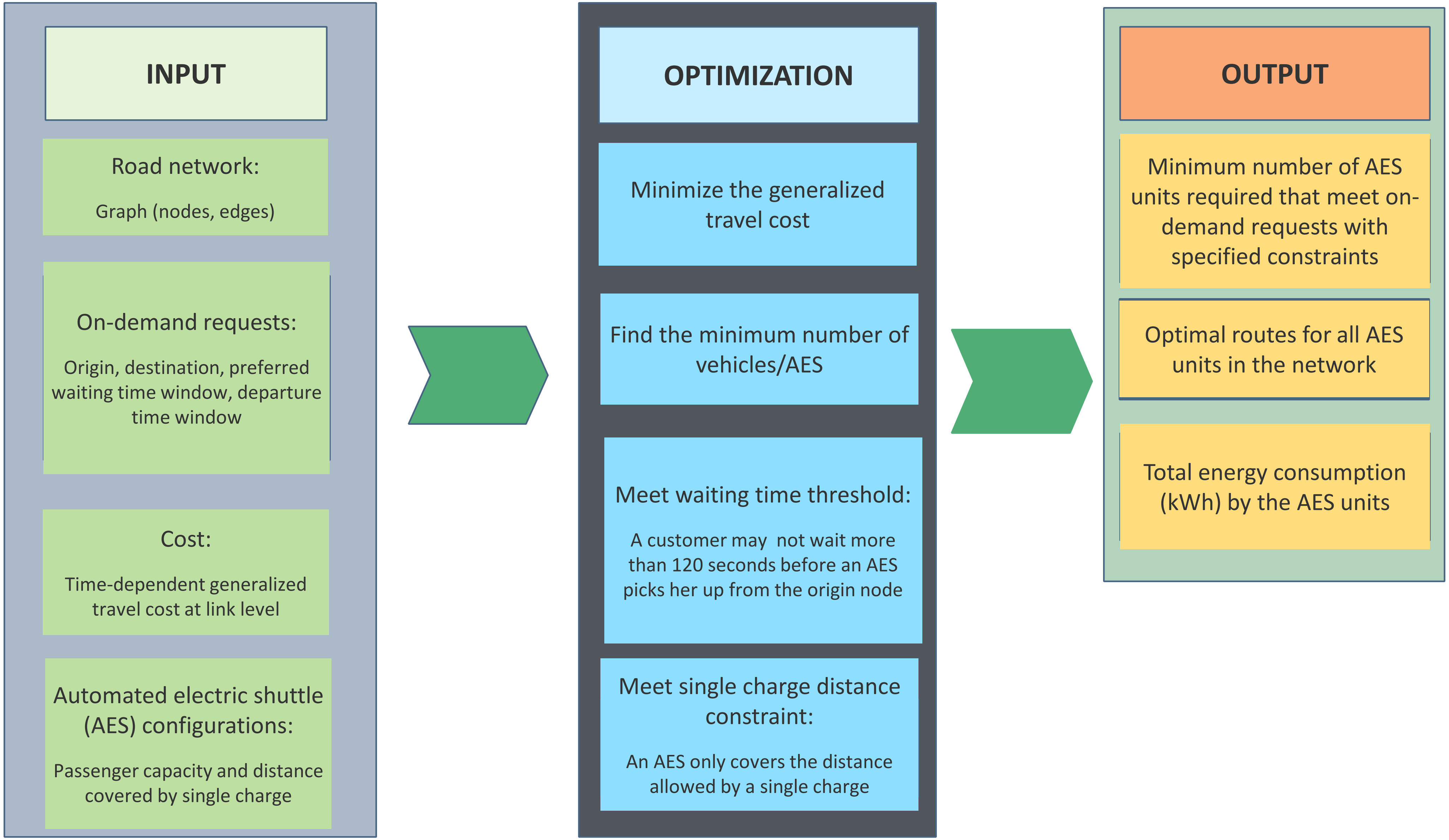
AMD Simulation Sample



```
Warning: Invalid route replacement for vehicle 'car_122'. No connection between edge '-366005186' and edge '12450780#2'.
Warning: Vehicle 'AES_3' will not be able to arrive at the given position!
```

'GV.sumocfg' loaded.

Optimization Framework: Workflow



INPUT

Road network:

Graph (nodes, edges)

On-demand requests:

Origin, destination, preferred waiting time window, departure time window

Cost:

Time-dependent generalized travel cost at link level

Automated electric shuttle (AES) configurations:

Passenger capacity and distance covered by single charge

OPTIMIZATION

Minimize the generalized travel cost

Find the minimum number of vehicles/AES

Meet waiting time threshold:

A customer may not wait more than 120 seconds before an AES picks her up from the origin node

Meet single charge distance constraint:

An AES only covers the distance allowed by a single charge

OUTPUT

Minimum number of AES units required that meet on-demand requests with specified constraints

Optimal routes for all AES units in the network

Total energy consumption (kWh) by the AES units

Optimization Model

Formulation

- The problem is formulated as a constrained mixed integer program
- Decision variables are integers
- Set of constraints are linear in nature
- Combinatorial problem

Challenges

- General solution approaches include branch-and-bound and cutting-plane methods
- Smaller networks can be solved using commercial solvers such IBM CPLEX and Gurobi
- Computational complexity rises with size of the graph (network) and the number of on-demand requests
- Exact solution methods are not scalable for large networks

Solution Approach: Tabu Search

- Two-phase heuristic:
  A. Initial routes construction
  B. Refinement satisfying the constraints
- Provides a feasible and near-optimal solution within acceptable time range
- To find the minimum number of vehicles required, we start with an upper bound and apply a bi-section search to obtain the solution

Comparison to exact-solution method

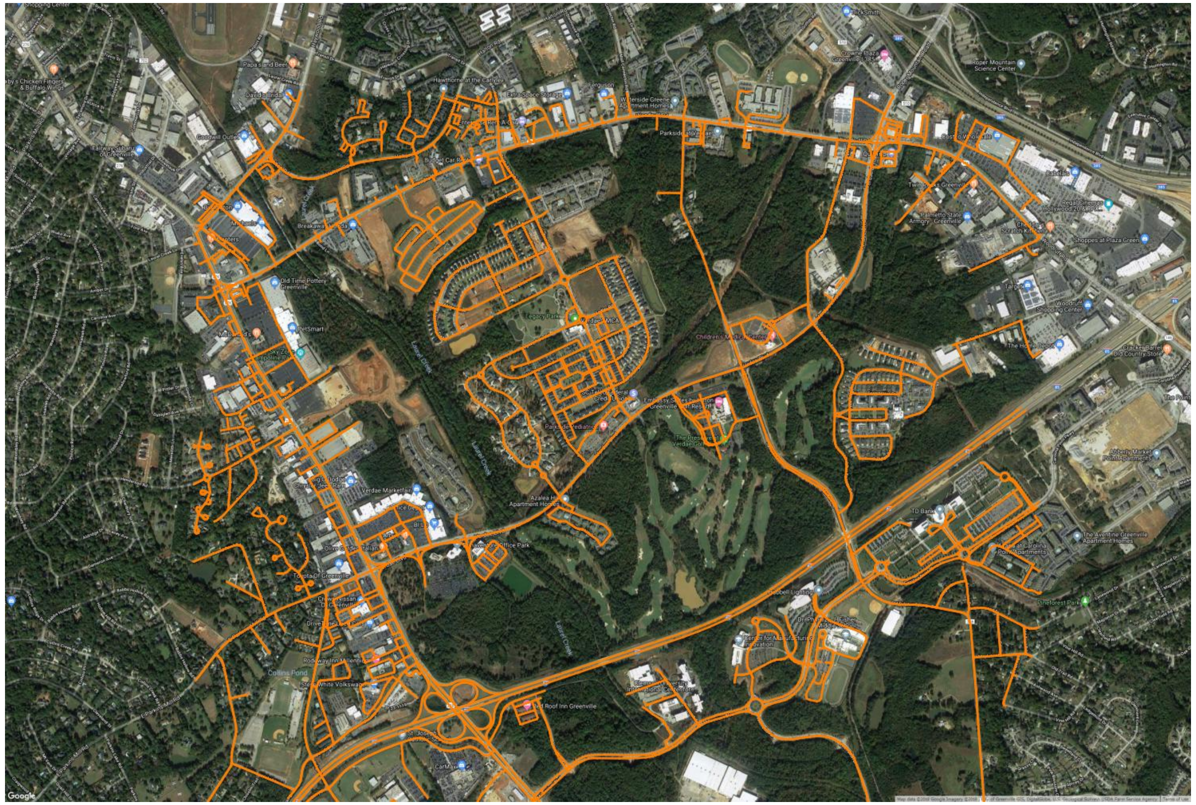
Test case	On-Demand Requests	Fleet Size	Cost (CPLEX)	Cost (Tabu Search)
A	6	2	48	49
B	6	3	59	59
C	7	2	50	51

We compared the solutions from the proposed Tabu search technique with the solutions obtained from applying an exact method using the CPLEX solver.

Both sets of solutions are obtained for a 15-by-15 grid network with origin-destination pairs set at the four corner points.

Case Study: Greenville, South Carolina

- Location: Greenville, South Carolina
- Analysis period: a.m. peak hour (6 a.m.–9 a.m.)
- The time-dependent demand distribution:
  - Known and deterministic
  - Total 378 trips
  - AMD share is about 50%
  - Distributed among eight traffic analysis zones
- AES configuration:
  - Capacity: 2, 4, and 8 passengers
  - Range: 20, 30, and 50 km

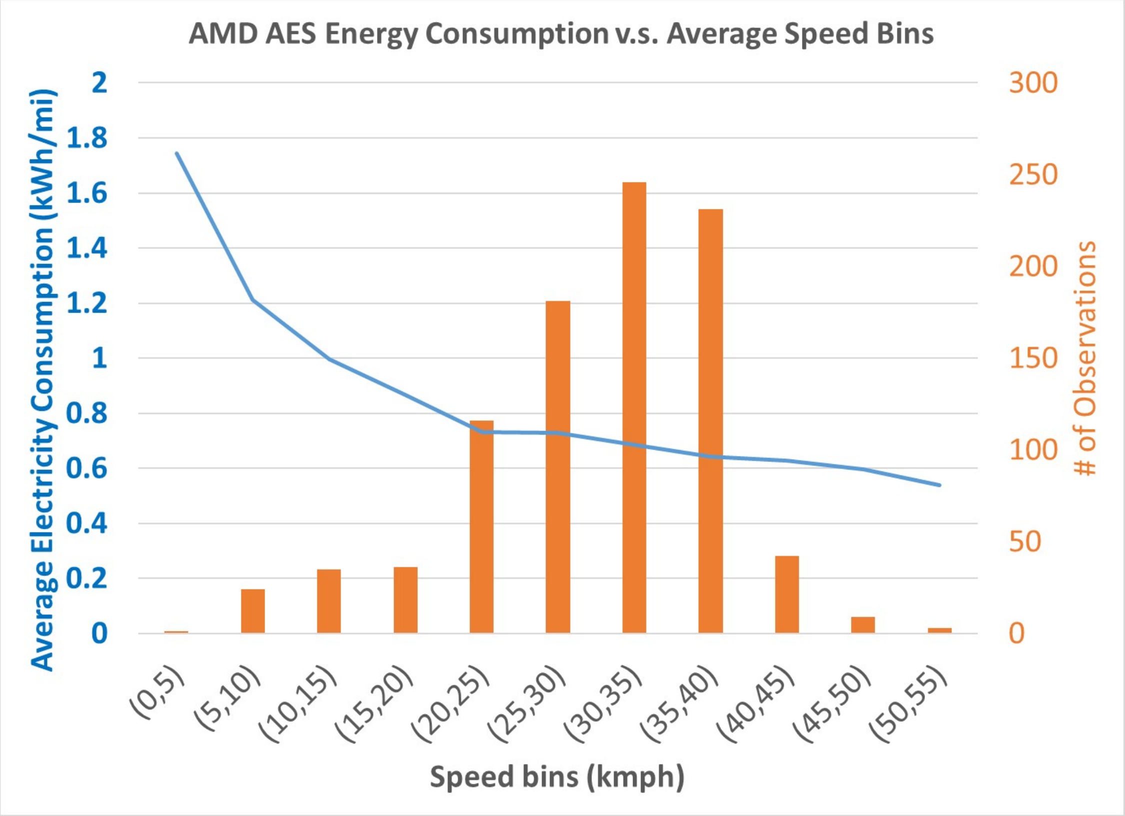


Greenville, South Carolina, network has 554 nodes and 1,340 edges

Travel Cost and Energy Consumption

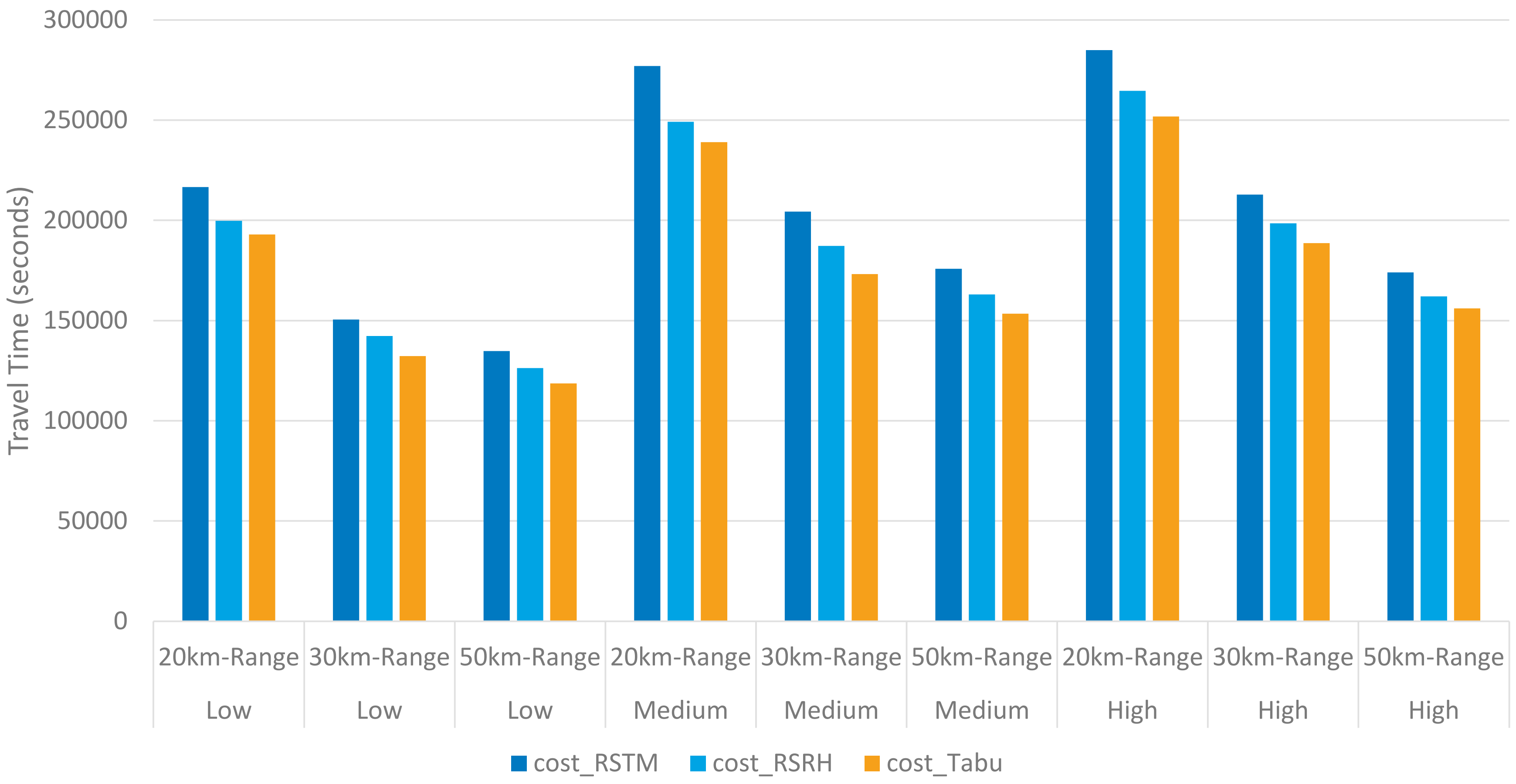
- Link travel time data are obtained from the microscopic traffic simulation tool, SUMO, at a resolution of 15 minutes
- We model the a.m. peak hour (6 a.m.–9 a.m.) in the Greenville, South Carolina, network
- We assume dynamic travel time that changes each 15-minute interval. Thus, we have (180/15) or 12 interval horizons

- An average speed and energy look-up table is developed using FASTSim**
- A relationship between average driving speed and energy consumption rate is developed using SUMO



**Brooker, A., Gonder, J., Wang, L., Wood, E. et al., "FASTSim: A Model to Estimate Vehicle Efficiency, Cost, and Performance," SAE Technical Paper 2015-01-0973, 2015, doi:10.4271/2015-01-0973.

Findings: Travel Time (Cost)



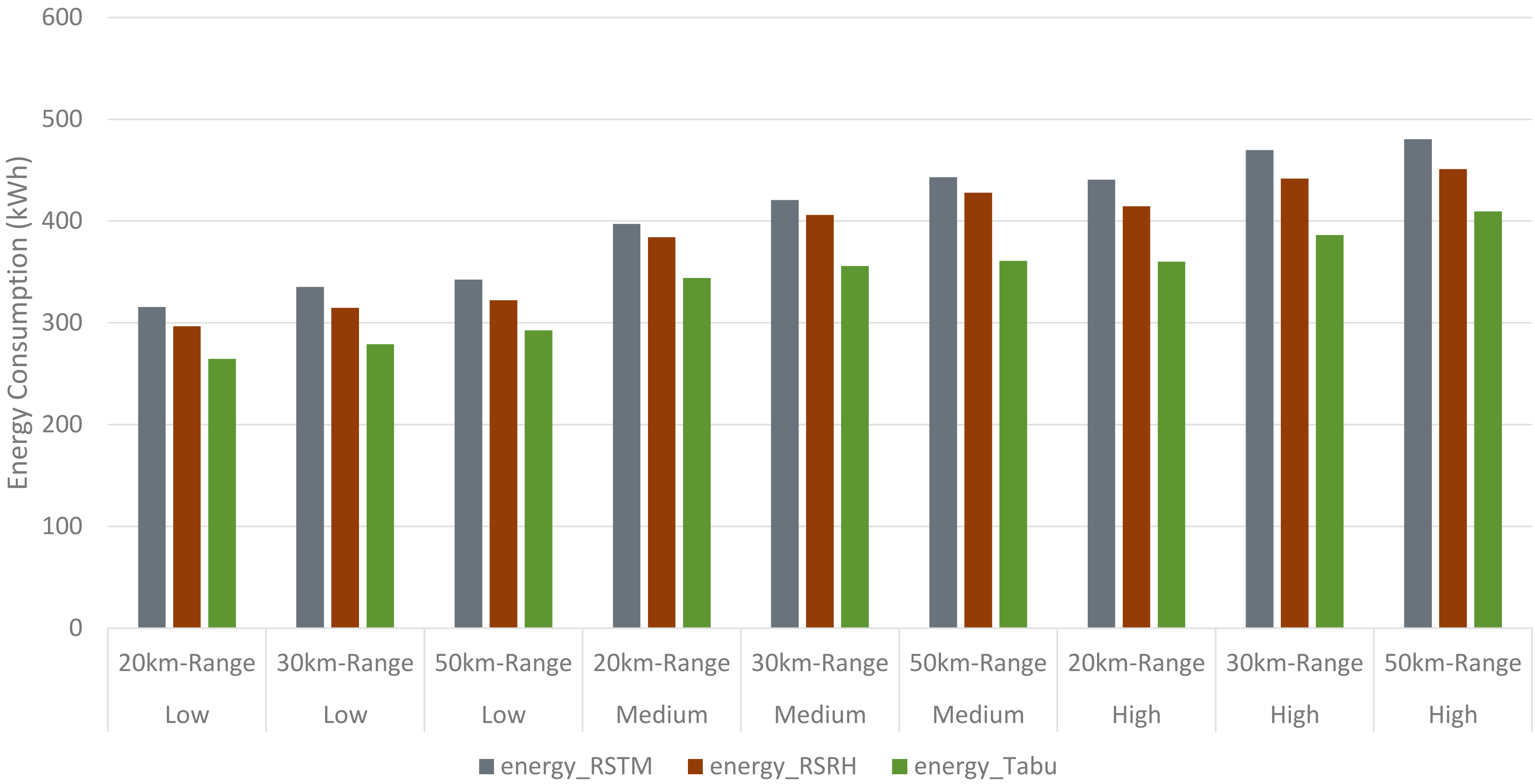
- Tabu search performs better compared with commonly used heuristics: RSTM and RSRH
- Tabu search provides lower travel time (cost) in all demand cases and all AES ranges (The overall savings ranges from 2-10%)

RSTM: Real-time solution with trip matching (RSTM) does not use any information regarding future demand for the AMD service.

RSRH: Real-time solution with rolling horizon (RSRH) routing uses limited information about future requests from the customers.

Demand: Low ➔ 134 requests; Medium ➔ 177 requests; High ➔ 194 requests

Findings: Energy Consumption



- ○ Energy savings compared with both RRTM and RSRH ranges from 9-18%.
- ○ For 30 km AES range, the relative energy savings are most significant

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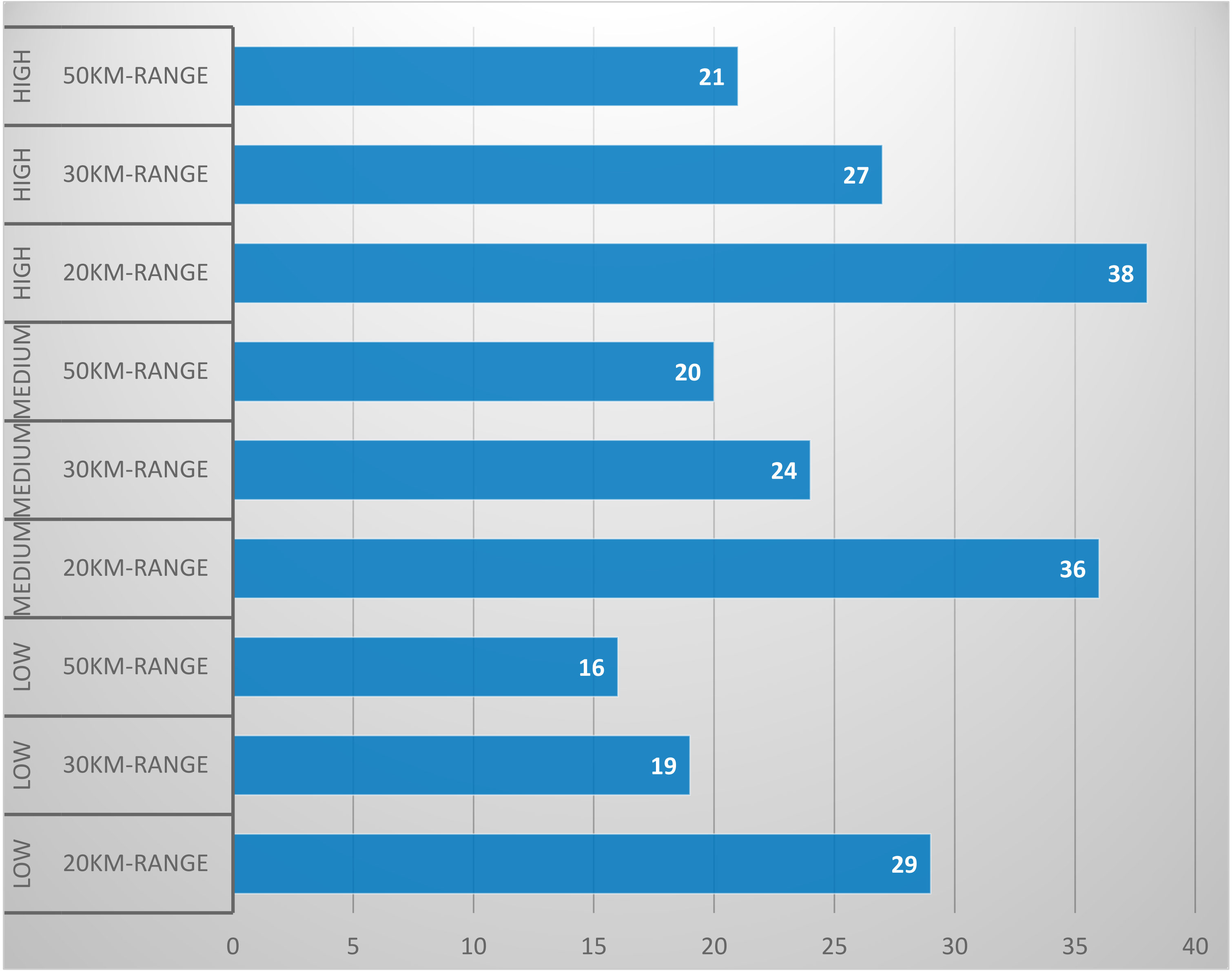
RSRH: Real-time solution with rolling horizon (RSRH) routing uses limited information about future requests from the customers.

Demand: Low ➔ 134 requests; Medium ➔ 177 requests; High ➔ 194 requests

Findings: Minimum Number of Vehicles Required



- The results are intuitive and conform to general expectations
- The minimum number of vehicles required rises with higher demand and shorter AES range
- Higher number of vehicles as the trips are heavily dispersed in space and time.

Next Steps

- GUI building for the ease of sensitivity analyses and on-demand mobility service operations
- Integration of more constraints
  - Soft time window for waiting time
  - Trip duration threshold for group rides
- Distributed optimization for scalability
- Extend to additional deployment/demonstration zones
- Release of open source AMD modeling and simulation package

Thank you

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