INL/MIS-20-58155-Revision-0

Charging Infrastructure Design Trade-offs for a Fleet of Human-Driven and Fully Automated Electric Vehicles in San Francisco

John G Smart

June 2020

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

CHARGING INFRASTRUCTURE DESIGN TRADE-OFFS FOR A FLEET OF HUMAN-DRIVEN AND FULLY AUTOMATED ELECTRIC VEHICLES IN SAN FRANCISCO

JOHN SMART
Idaho National Laboratory

2020 DOE Vehicle Technologies Office Annual Merit Review

INL/MIS-20-58155

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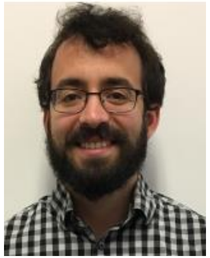
Argonne NATIONAL LABORATORY · BERKELEY LAB · INL Idaho National Laboratory · NREL NATIONAL RENEWABLE ENERGY LABORATORY · OAK RIDGE National Laboratory

PROJECT TEAM

Timothy Lipman, PhD
LBNL / UC Berkeley



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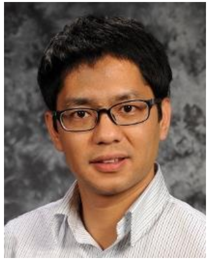

Zonggen Yi, PhD
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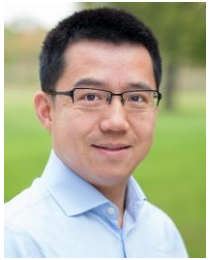

Zhi Zhou, PhD
ANL

OVERVIEW

Timeline

- Start: October 2016
- End: September 2019
- 100% Complete

Budget

- Total: $1,235K
- FY19: $640K
  - INL $310K
  - LBNL $125K
  - NREL $155K
  - ANL $50K
- FY18: $425K
- FY17: $270K

Barriers

- The influence of charging infrastructure availability on shared mobility is not yet well understood
- High risk to develop and deploy advanced vehicles and infrastructure

Partners

- SMART Mobility Laboratory Consortium partners: INL (lead), LBNL, NREL, ANL
- Data providers: Populus, RideAustin

RELEVANCE TO VTO GOALS

Advanced Fueling Infrastructure Pillar

- Transportation electrification has significant potential to increase mobility energy productivity, *provided that* adequate charging infrastructure is available

- This project focused on understanding the costs and benefits of charging infrastructure to support energy efficient ride-hailing

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THE QUESTION

What charging infrastructure do we need for electric ride-hailing vehicles in the future?

WAMU, AUG 14, 2017

With No Place To Charge, D.C.'s Electric Cab Drivers Ask For Help

District's Eco-Friendly Cab Program Suffers From Lack Of Charging Stations

September 26, 2019

EVgo and Uber Announce Partnership to Accelerate Rideshare Electrification

Source: shutterstock.com

Source: INL

https://wamu.org/story/17/08/14/no-place-charge-d-c-s-electric-cab-drivers-ask-help/
https://www.evgo.com/about/news/evgo-and-uber-announce-partnership-to-accelerate-rideshare-electrification/

THE ANSWER

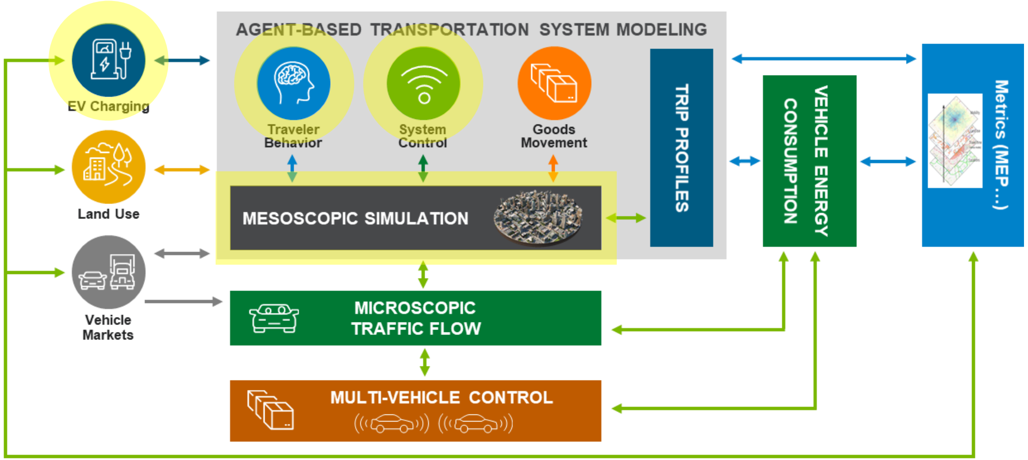
- There is no “right” amount of charging infrastructure

- Different amounts and types afford different levels of service
- In some cases, adding more charging infrastructure offers minimal to no incremental benefit
- What we need is a way to quantify trade-offs

CHARGING INFRASTRUCTURE DESIGN TRADE-OFFS

Project Objectives

- Examine the charging needs of a fleet of both human-driven and automated electric ride-hailing vehicles (AEVs)
- Use sophisticated modeling tools to understand trade-offs between charging infrastructure network design, mobility, energy consumption, and cost
- Conduct case study in San Francisco Bay Area



SMART Mobility Modeling Workflow with tools highlighted that were used in this project

APPROACH

TWO APPROACHES TO CHARGING STATION SITING

Created “Rich” and “Sparse” DC fast charging networks

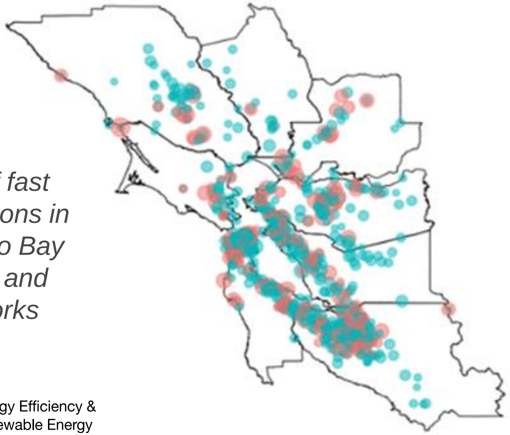
Rich

- Demand-based approach to create ideal charging availability
- EVI-Pro and FCSPlan designed charging infrastructure to satisfy all demand for charging

Sparse

- Trend-based approach following pattern of today’s networks to reflect real-world constraints
- Increased number of stations by 50%, siting them at similar locations and with similar number of plugs as today’s stations

Maps show distribution of fast charging stations in San Francisco Bay Area for Rich and Sparse networks



Depot chargers for automated ride-hailing EVs

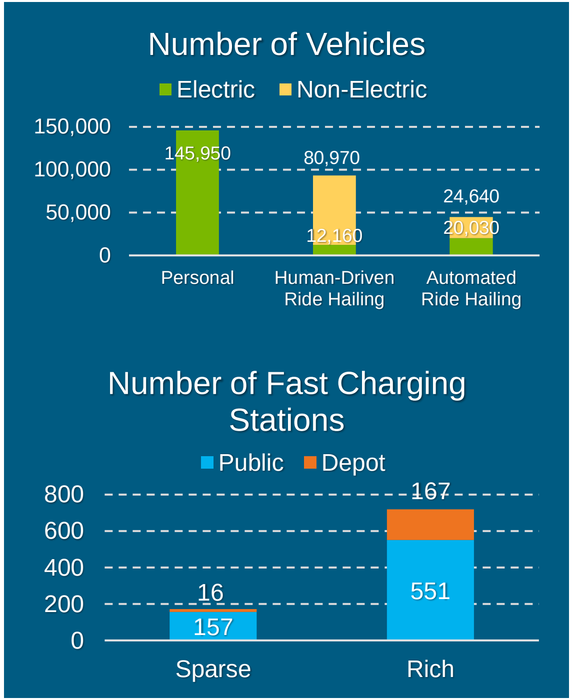
Public chargers for human-driven ride-hailing and personal-use EVs

SIMULATION APPROACH

BEAM simulation of traveler behavior and ride-hailing fleets

- Used a SMART Mobility common modeling scenario*
  - Ride-hailing fleet was a mix of human-driven vehicles and AEVs
  - Traveler preferences were weighted toward shared modes

- Ran 24 variations, changing the following parameters:
  - Charging network size/density (Sparse, Rich)
  - Charge power (50 kW, 100 kW)
  - Vehicle EV range (100, 200, 300 miles)



* Used SMART Mobility Workflow Common Scenario B5

KEY PERFORMANCE INDICATORS

Customer wait time

Vehicle miles traveled (VMT)

Energy consumption

Deadheading miles traveled

Vehicle idle time between rides

Vehicle time out of service (i.e., downtime)

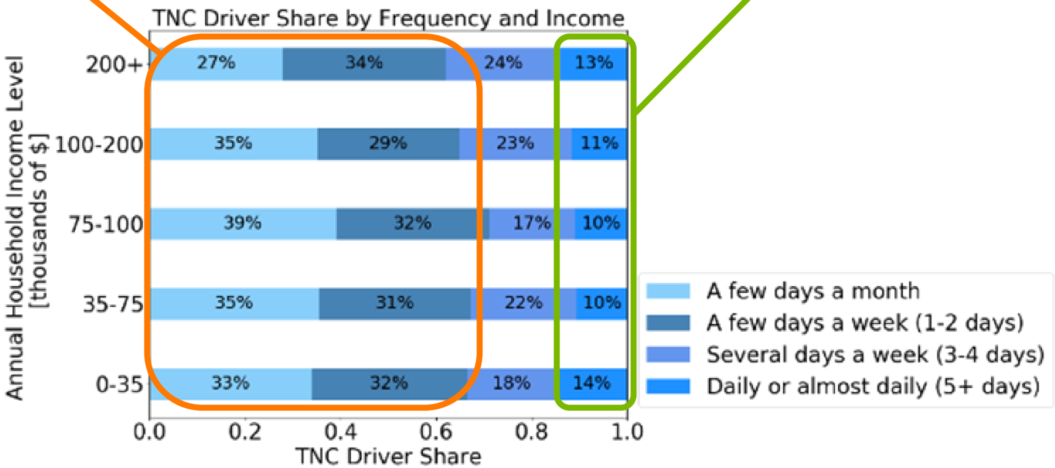
Passenger miles traveled (PMT)

Fleet operating cost ($ / PMT)

MODELING DRIVING BEHAVIOR

Most transportation network company (TNC) drivers are part-time

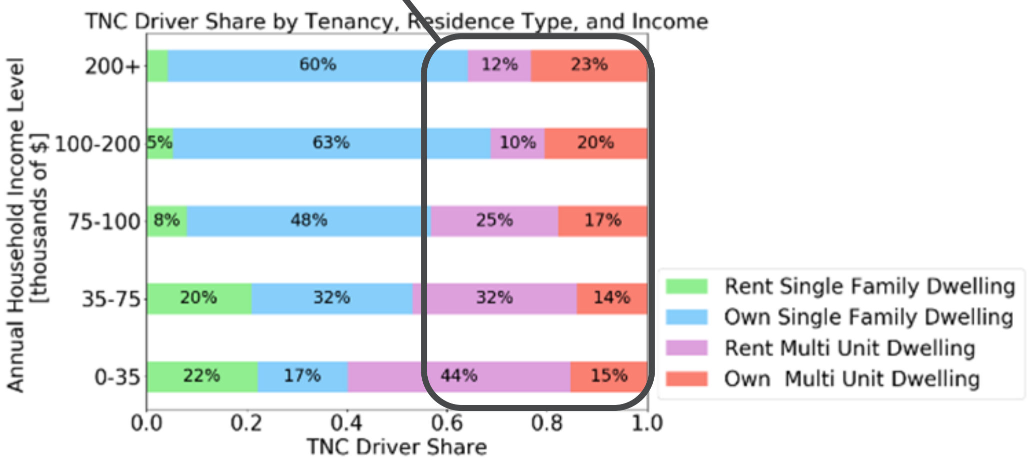
- Results from survey of 1,000+ TNC drivers in 10 cities showed that only ~10% drive for a TNC daily
- Over half of drivers drive for TNC for two days/week or less
- In 24-hour simulation, we applied distribution of number of drivers driving that day, shift start time, and shift length (average of 3.5 hours)
- In contrast, AEVs were assumed to be on shift continuously



MODELING CHARGING BEHAVIOR

Assumed Half of Drivers Have Access to Home Charging

- Populus survey reported 40% of TNC drivers live in multi-unit dwellings where home charging is traditionally problematic
- Maven reported 95% of Chevy Bolt short-term lessees driving for Lyft could not charge at home
- In simulation, we assumed a uniform distribution for SOC at the start of the day



TECHNICAL ACCOMPLISHMENTS (FINAL RESULTS)

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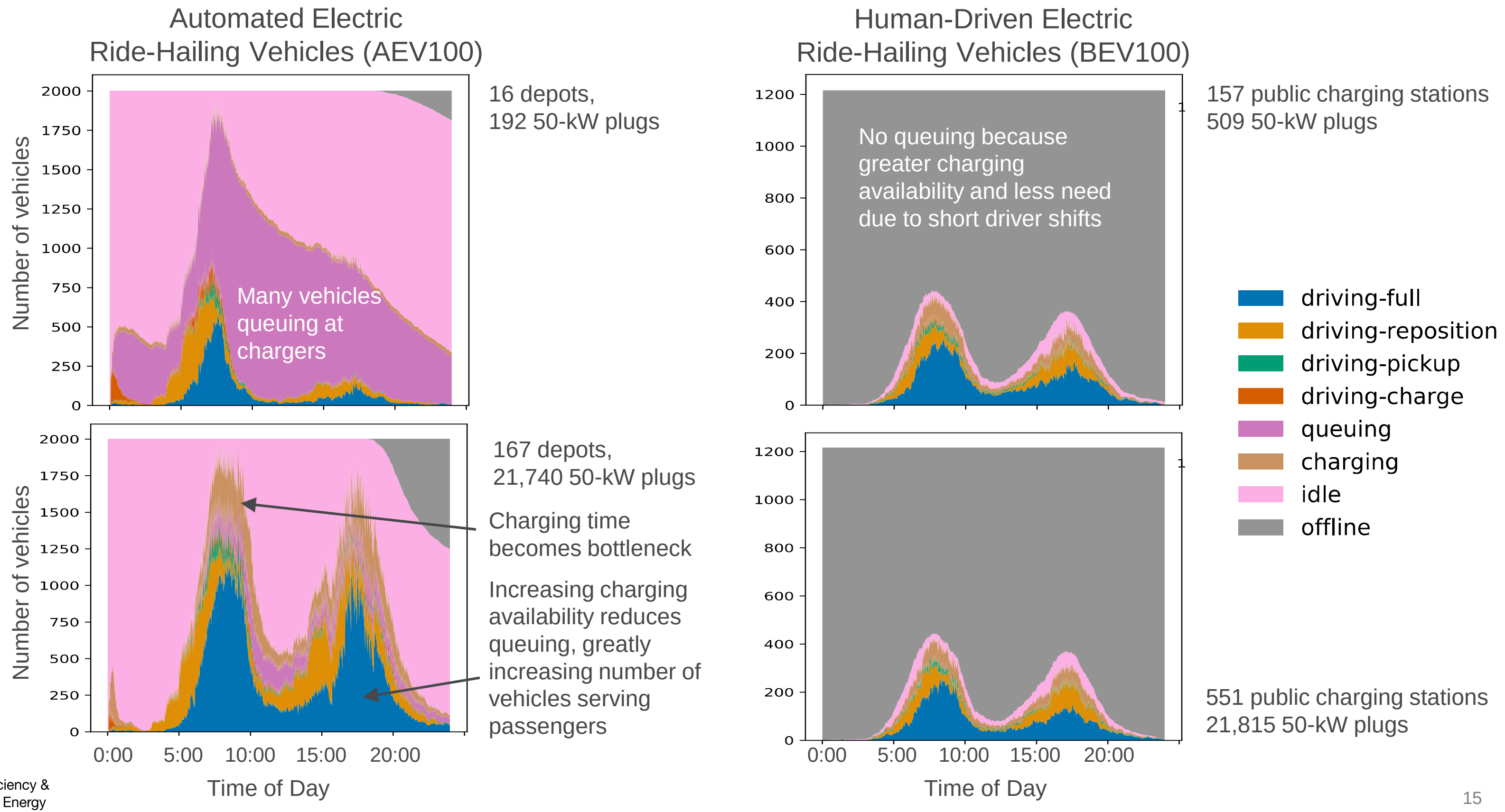
SIMULATION RESULTS: BASE CASE

Sparse 50-kW network creates extreme queuing for AEV100s

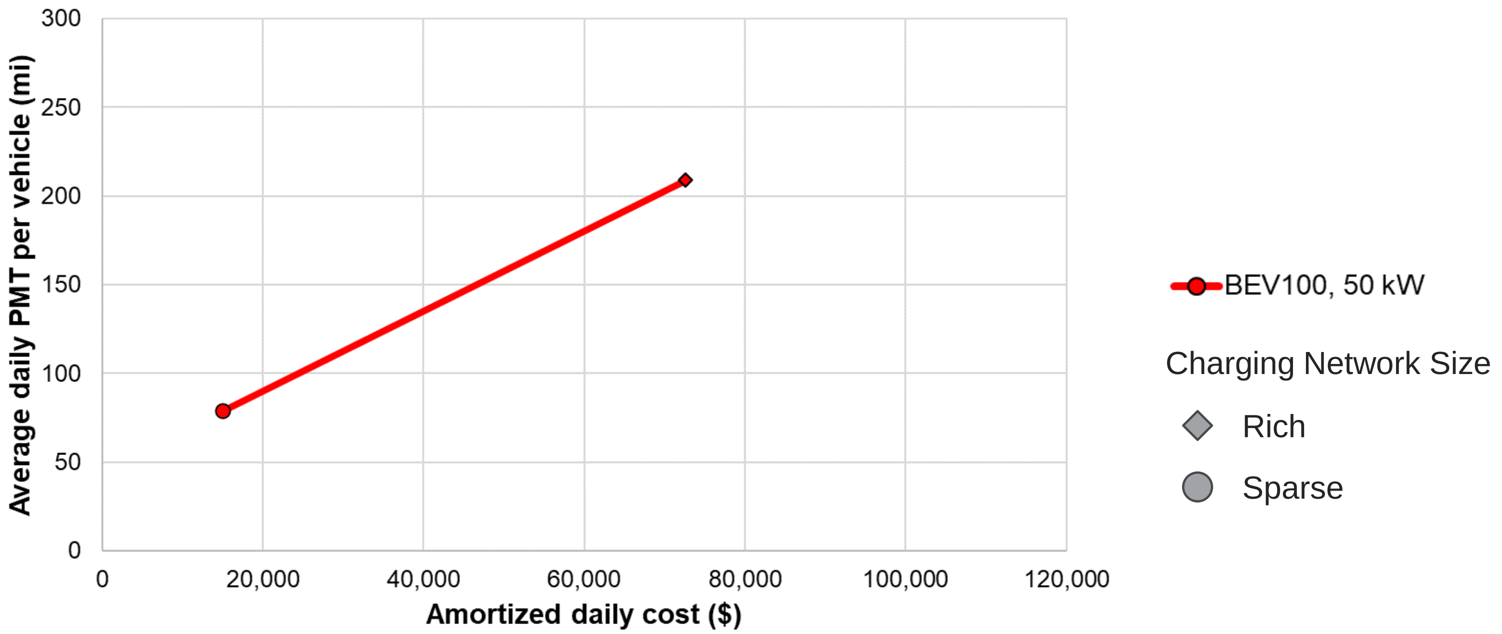
Sparse Infrastructure

Rich Infrastructure



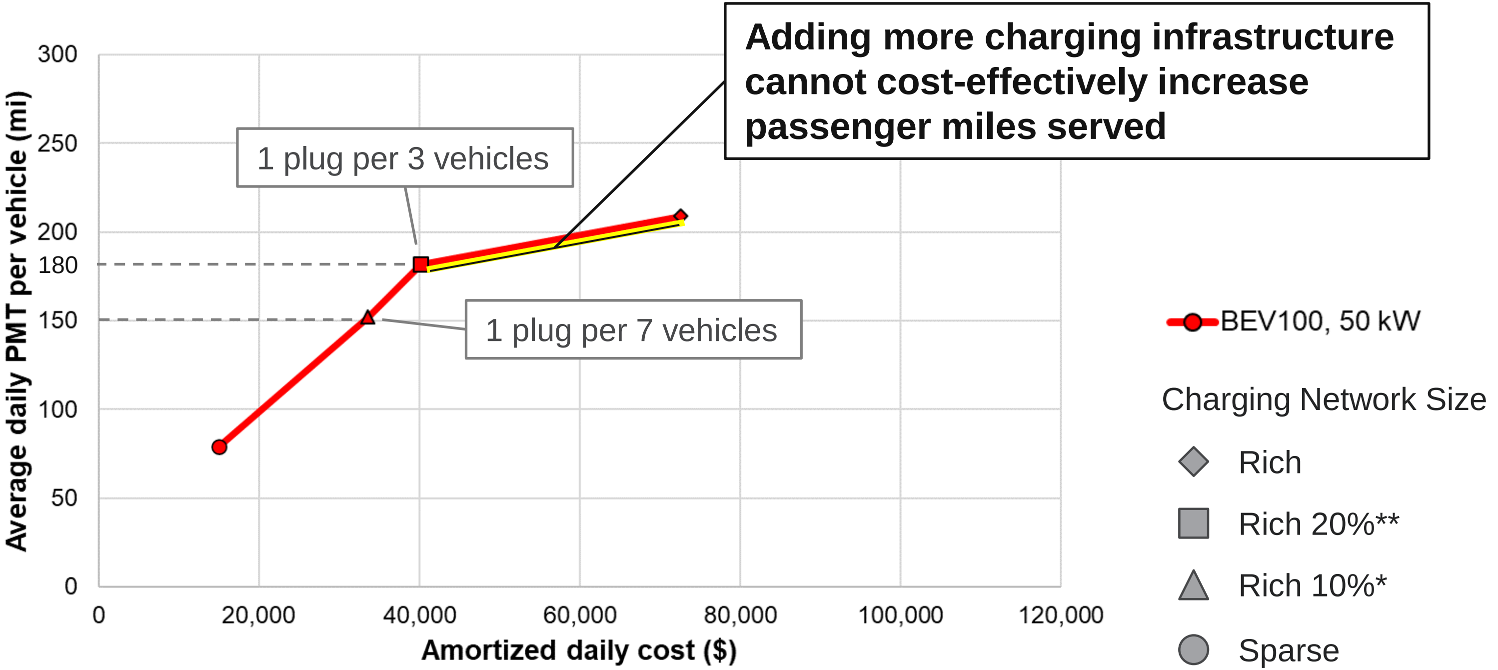
QUANTIFYING CHARGING NETWORK COST AND BENEFIT TO THE FLEET

Charging network size affects fleet's capacity to serve passengers



INTERMEDIATE CHARGING NETWORK SIZES ADD CLARITY

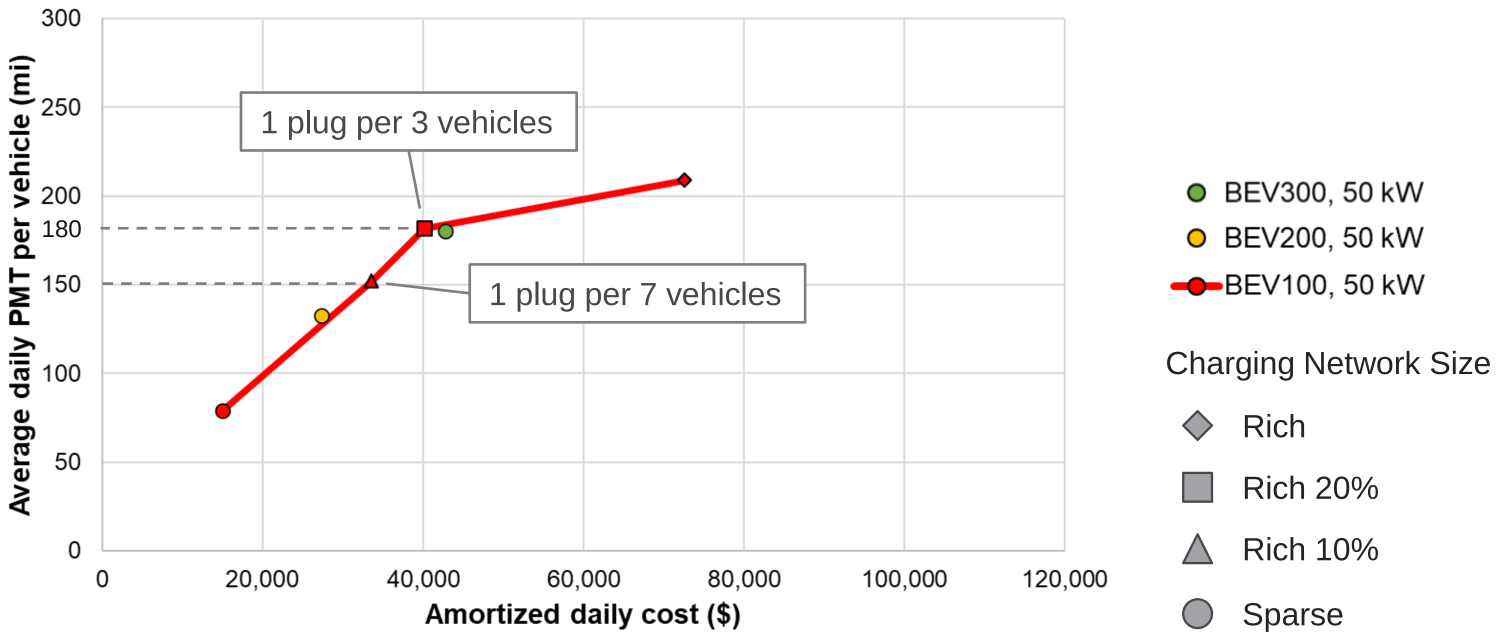
PMT served is linear with cost until point of diminished returns



** Rich 20% has same number of stations as Rich but 20% of the plugs
* Rich 10% has same number of stations as Rich but 10% of the plugs

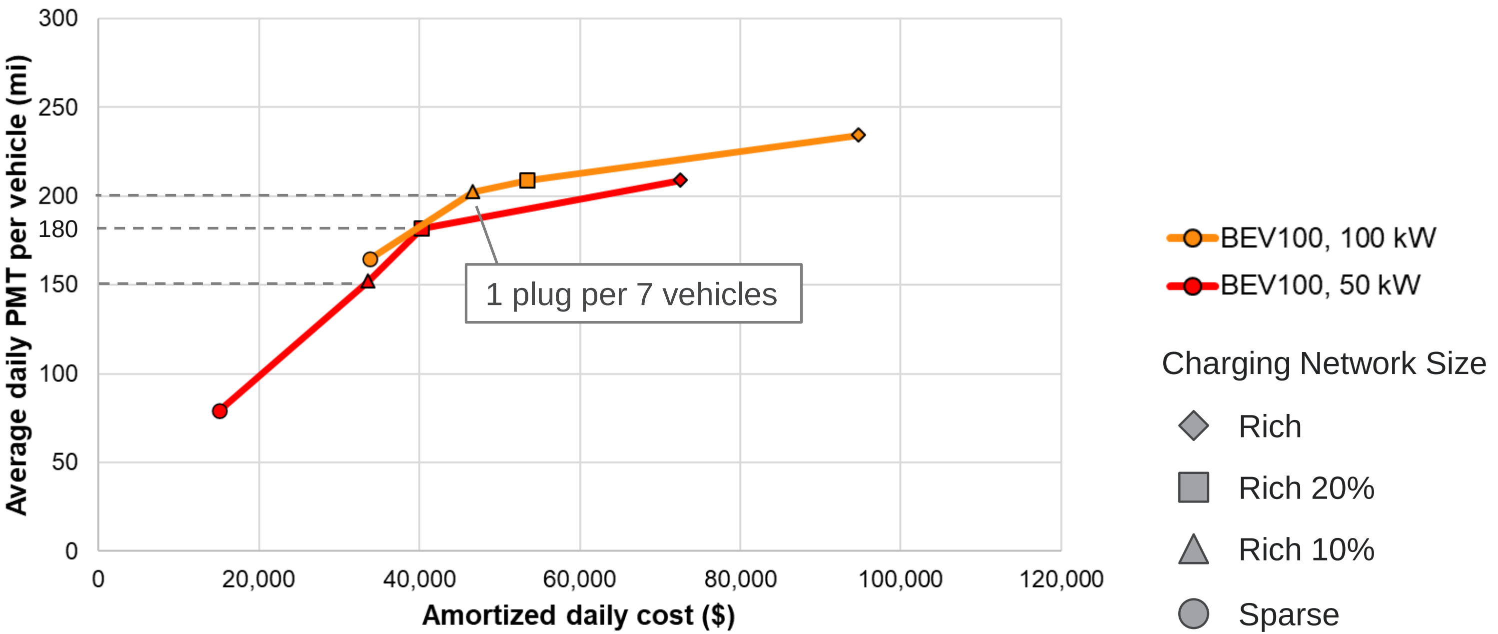
INCREASING EV RANGE INCREASES PMT

Provides same rate of return as increasing charging network size



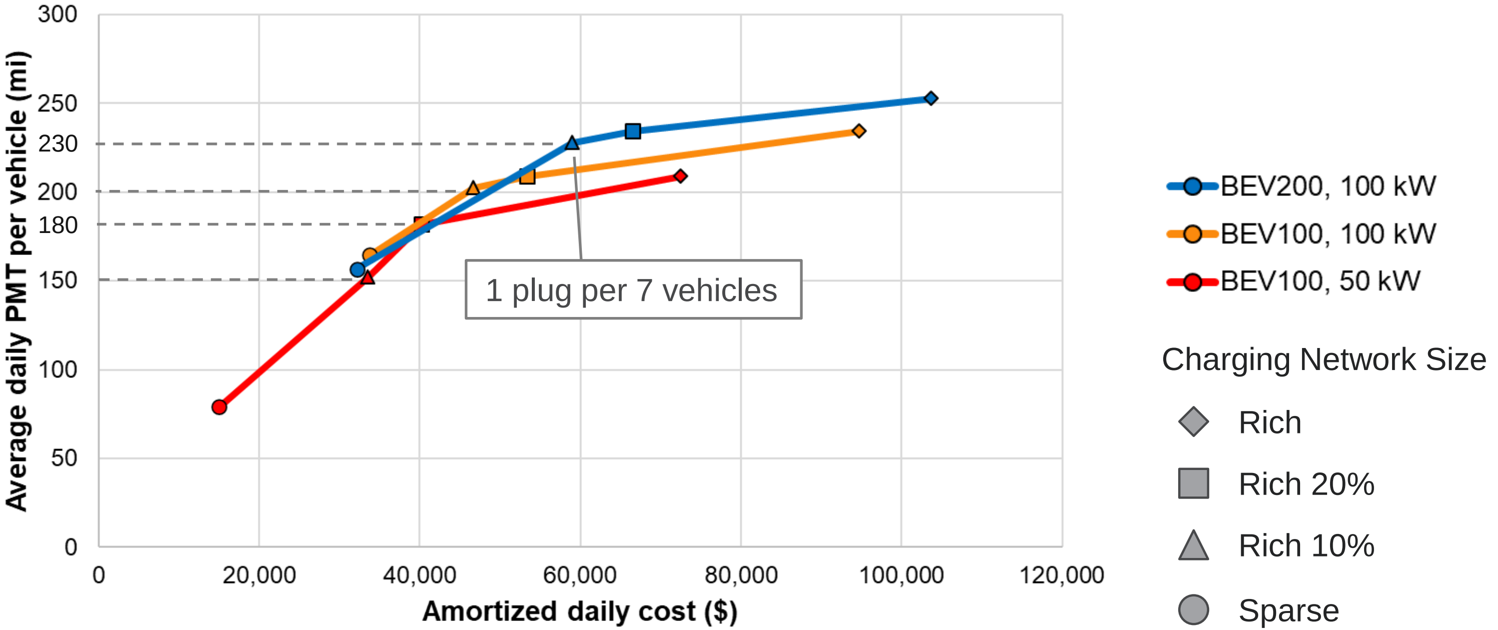
INCREASING CHARGE POWER SURPASSES PMT THRESHOLD

Upgrading to 100-kW charging cost-effectively increases PMT to 200 mi/day per vehicle



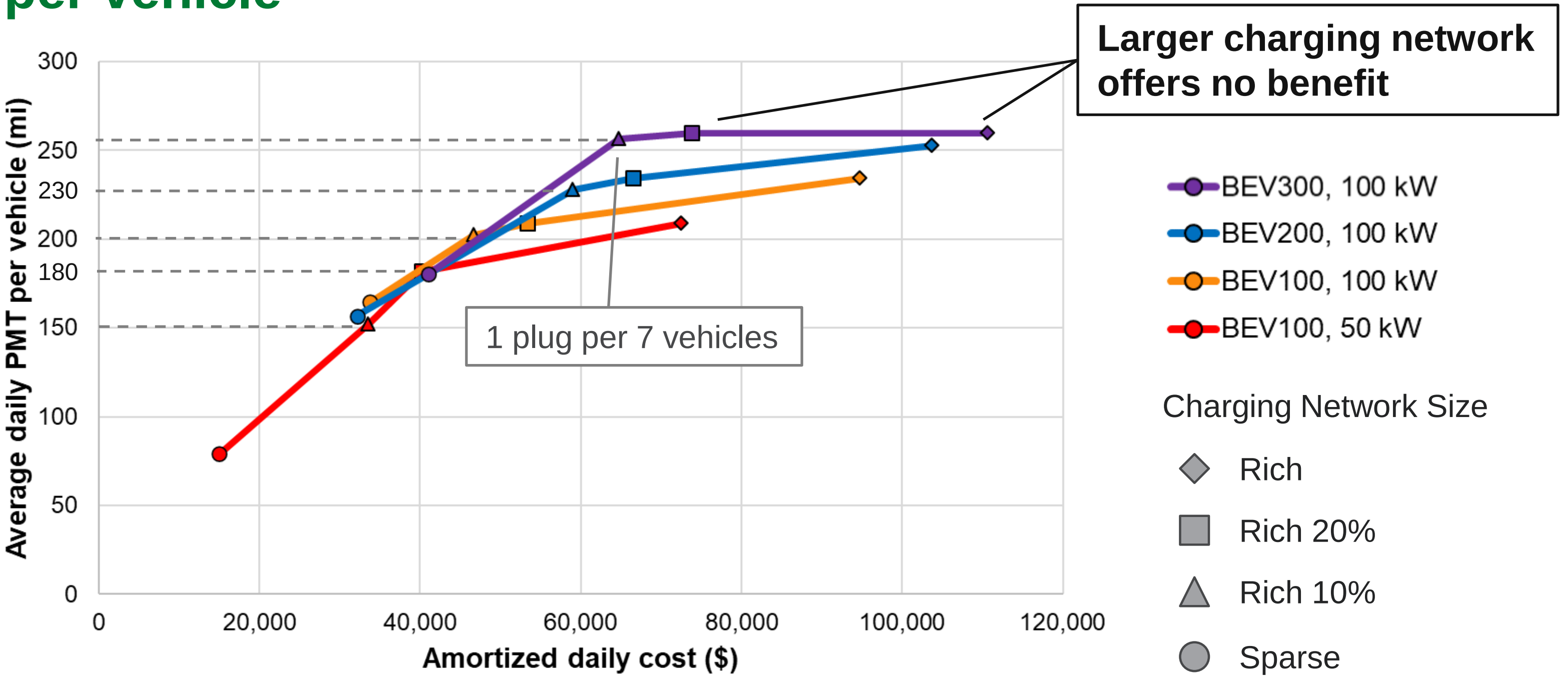
INCREASING CHARGE POWER *AND* EV RANGE INCREASES PMT FURTHER

BEV200s with widespread 100-kW charging cost-effectively serve 230 passenger mi/day per vehicle



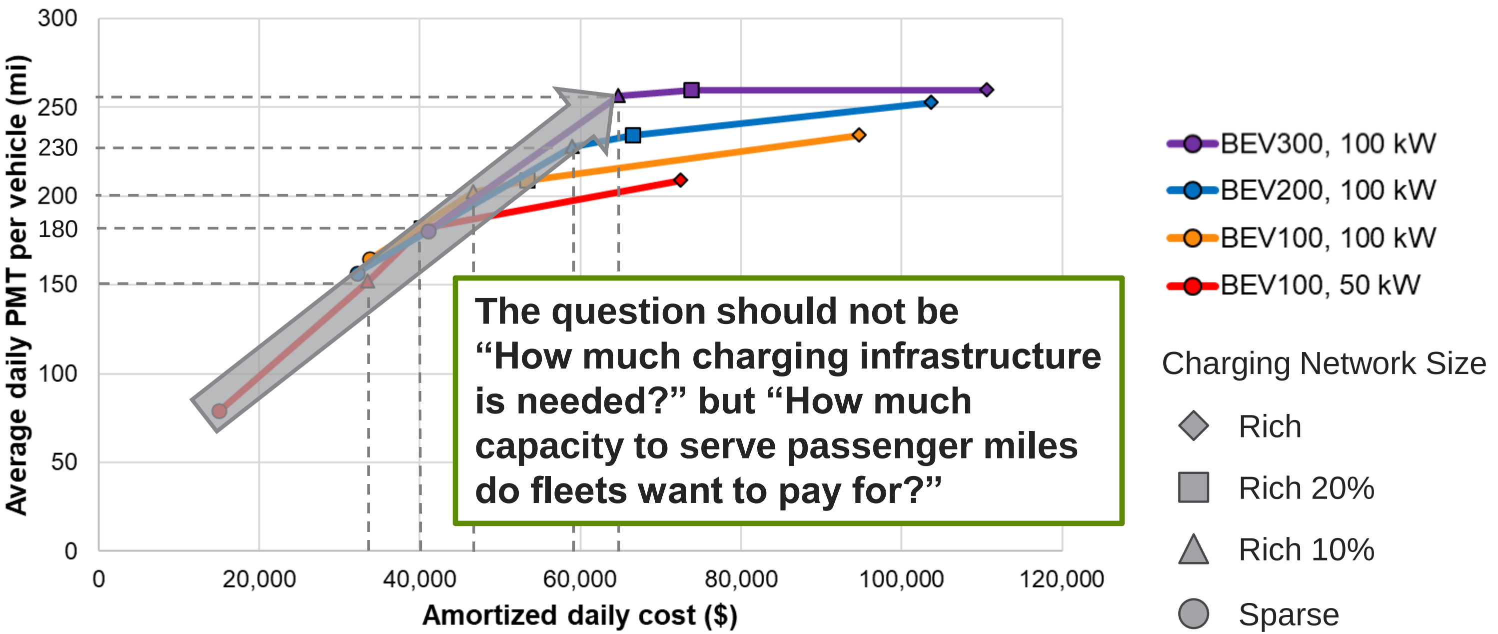
TREND HOLDS WHEN INCREASING EV RANGE FURTHER

BEV300s with widespread 100-kW charging surpass 250 passenger mi/day per vehicle



DIFFERENT SOLUTIONS AFFORD DIFFERENT LEVEL OF SERVICE

Quantifying level of service vs. cost prompts a new question



The question should not be "How much charging infrastructure is needed?" but "How much capacity to serve passenger miles do fleets want to pay for?"

RESPONSE TO PREVIOUS YEAR REVIEWER COMMENTS

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1. "There are charging stations installed in public venues to allow the public to charge EVs outside of their homes. It is not clear whether these were included in the availability for ride-share vehicles."
   - Simulation allowed both human-driven ride-hailing EVs and personal-use EVs to use public charging stations. The personal-use EV fleet was simulated to create competition for charging.

2. "There are real world scenarios already taking place as charging models…. It probably would be better served to look at what is already out there and look at improving or upgrading the model."
   - For this reason, the Sparse charging network was included to reflect continuation of the current market model for charging station deployment.

3. "As the electric technology gets better, the infrastructure needs to keep up with the vehicle advances not only in hardware to support it, but places to fuel it in the most efficient way…."
   - The results of this project emphasize the need to take a systems approach. We must evaluate vehicle technology and charging infrastructure together to design an efficient system. It's not just about adding more charging stations.

COLLABORATION AND COORDINATION

DOE SMART Mobility Laboratory Consortium participants:

- Idaho National Laboratory
  - Use case development, charging infrastructure network design, trade-off analysis
- Lawrence Berkeley National Laboratory
  - Cost modeling, BEAM development for specific use cases, simulation, and trade-off analysis
- National Renewable Energy Laboratory
  - Data collection and analysis of TNC data, behavioral modeling
- Argonne National Laboratory
  - Charging infrastructure network design and cost modeling

Data partners: Populus, RideAustin

REVISITING THE QUESTION

What charging infrastructure do we need for electric ride-hailing vehicles in the future?

… AND THE ANSWER

- **There is no "right" amount of charging infrastructure – different amounts afford different levels of service**
- **To manage cost/benefit trade-off, must define desired level of service**

To exceed 200 PMT/day per vehicle in the San Francisco case study, adding more charging infrastructure is not enough, even if chargers are optimally sited

- 100+kW charging and 200+ mile EV range are also needed

More charging stations are not always better

- When factoring in real estate costs, building a sparse charging network of high-power chargers is more likely to meet service requirements at lower cost

PROPOSED FUTURE RESEARCH

Economically viable, grid-integrated charging infrastructure is needed to serve personal-use and ride-hailing EVs nationwide

Building on this project, additional research should be conducted to:

- Improve models and conduct simulations for multiple cities to produce generalizable results
  - Expand EV and TNC data collection to better model EV driving and charging behavior
  - Apply alternate cost models (e.g., include 3rd party charging network provider)
  - Incorporate strategies developed in EEMS038 for intelligently managing AEV ride-hailing fleets to understand potential for efficiency improvements
- Partner with industry to validate simulation results and apply insights gained
  - Compare to level-of-service targets for electric ride hailing fleets
- Assess barriers to scaling AEVs fleets and charging infrastructure across cities and regions

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MOBILITY FOR OPPORTUNITY

FOR MORE INFORMATION
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TECHNICAL BACK-UP SLIDES

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SIMULATION INPUT PARAMETERS

Topic	Assumptions	Value	Notes
Vehicle Properties	Vehicle range	100/200/300 miles	All BEVs were given the same range
Ride-Hailing Fleet Size	Total # Vehicles	137,800	
Personal-Use Fleet Size	# EVs	145,950	
Charging-Power Capacity	Power capacity of fast chargers	50/100 kW	All charger plug power levels assumed the same within a scenario
Public Fast Charging Network Size (Number of stations / number of plugs)	Sparse	157 / 509	Public network is used by human-driven ride-hailing and personal-use EV drivers
	Rich 10%	551 / 2,311	
	Rich 20%	551 / 4,363	
	Rich 100%	551 / 21,815	
Depot Fast Charging Network Size (Number of stations / number of plugs)	Sparse	16 / 192	Depot network is used only by ride-hailing AEVs
	Rich 10%	167 / 2,174	
	Rich 20%	167 / 4,384	
	Rich 100%	167 / 21,740	

COST MODEL INFORMATION

Human-driven BEV purchase cost

- BEV100: $34.5K
- BEV300: $43.5K

Automated electric vehicle (AEV) purchase cost

- AEV100: $41.4K
- AEV300: $52.2K

Additional costs for maintenance, insurance, etc.

Ride-hailing fleet assumed to own and operate all charging stations

Installed costs for commercial-grade DC fast chargers by power capacity

- 50-kW: $46K
- 100-kW: $94K

Electricity cost

- Energy charge: $0.20/kWh
- Demand charge: $13.75/kW (monthly peak)

Additional costs for maintenance, insurance, etc.

REVIEWER-ONLY SLIDES

PUBLICATIONS AND PRESENTATIONS

- Zhang, H., C.J.R. Sheppard, T.E. Lipman, T. Zeng, and S.J. Moura (2020). Charging Infrastructure Demands of Shared-Use Autonomous Electric Vehicles in Urban Areas. Transportation Research Part D: Transport and Env't 78: 102210.
- Zhang, H., C.J.R. Sheppard, T.E. Lipman, and S.J. Moura (2019), "Joint Fleet Sizing and Charging System Planning for Autonomous Electric Vehicles," IEEE Intelligent Transportation Systems Transactions, 10.1109/TITS.2019.2946152.
- Wenzel, T., Rames, C., Kontou, E., & Henao, A. (2019). "Travel and Energy Implications of Ride-hailing Service in Austin, Texas." Submitted to Transportation Research Part D.
- Lipman, T., J. Szinai, E.A. Iosifidou, & M. Ghamkhari (2019), "Integration of Charging and Fueling Infrastructure with the Built Environment for Future Fleets of Advanced Vehicles." Lawrence Berkeley National Laboratory, Energy Analysis and Environmental Impacts Division, LBNL technical report. Under DOE review.
- Moniot, M., Rames, C., and Burrell, E., "Feasibility Analysis of Taxi Fleet Electrification using 4.9 Million Miles of Real-World Driving Data," SAE Technical Paper 2019-01-0392, 2019. Presented at 2019 SAE World Congress in Detroit, MI.
- Motoaki, Y. "Location-Allocation of Electric Vehicle Fast Chargers—Research and Practice." World Electric Vehicle Journal. 2019; 10(1):12. Presented at EVS31 in Kobe, Japan.
- Salisbury, Shawn. "SMART Mobility – Advanced Fueling Infrastructure." TRB 97th Annual Meeting. 8 Jan 2018, Washington, DC.
- Smart, John. "Energy Efficient Mobility Systems: The US DOE's Research on SMART Mobility – Advanced Fueling Infrastructure Pillar." ITS World Congress 2017. 31 Oct 2017.

CRITICAL ISSUES AND ASSUMPTIONS

- Rich 100% charging network is unrealistically large. It was chosen to explore the full range of system behavior
- Relatively simple cost models were used
  - Charging station installation cost varies widely by location and according to numerous factors. It is impossible to formulaically predict cost, so cost estimates are based on averages
  - AEV purchase prices derived from literature review but not confirmed by industry
  - Behavioral economics factors, such as public charging pricing elasticity, will likely have a large impact on behavior, but these are difficult to model due to lack of data
- Technologies and markets are rapidly advancing; complex business partnerships and business models are evolving rapidly that will change critical assumptions

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