Final Technical Report-WestSmart EV: Western Smart Plug-in Electric Vehicle Community Partnership

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Awardee: PacifiCorp

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Team Members:
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Executive Summary

The WestSmartEV (WSEV) project has accelerated adoption of plug-in electric vehicles (PEV) throughout the PacifiCorp/Rocky Mountain Power's (RMP) service territory in the intermountain west by developing a large-scale, sustainable PEV charging infrastructure network with coordinated PEV adoption programs. The project objectives have strategically deployed 79 DC fast charging to create two primary electric interstate highway corridors along I-15 and I-80; incentivized installation of Level 2 AC chargers at workplace locations; incentivized the purchase of PEVs; provided all electric solutions for first-mile and last-mile trips, including electrified mobility service; provided centralized data collection, analysis, modeling, and tool development to inform investment and policy decisions; and developed education outreach materials and conducted workshops across the WSEV region.

The overall target of the project was to double the growth rate for PEVs in communities in RMP's electric service territory, from 20% to 40%, leading to more than 50,000 PEVs within 10 years. The project developed a PEV adoption model predicting the impact of the project. It is expected that the total PEV sales by 2026 will reach 56,870. Without the WSEV programs, the predicted total PEV sales by 2026 would only be 34,475. The results demonstrate that, due to the deployment of chargers and other WSEV program and activities, the PEV adoption in Utah has been and will continue to be significantly accelerated. This is confirmed by actual registrations in the state of Utah. According to the Utah DMV in 2017 at the start of the WSEV project there were 2,485 PEVs registered in Utah, by 2020 there were 12,522 PEVs registered in the state, roughly a 500% increase.

Approach

To accomplish the primary project objective of increasing PEV adoption across the intermountain multi-state region, this project has implemented a three-year, strategically phased, directed, and coordinated implementation plan, as shown in Figure 1.

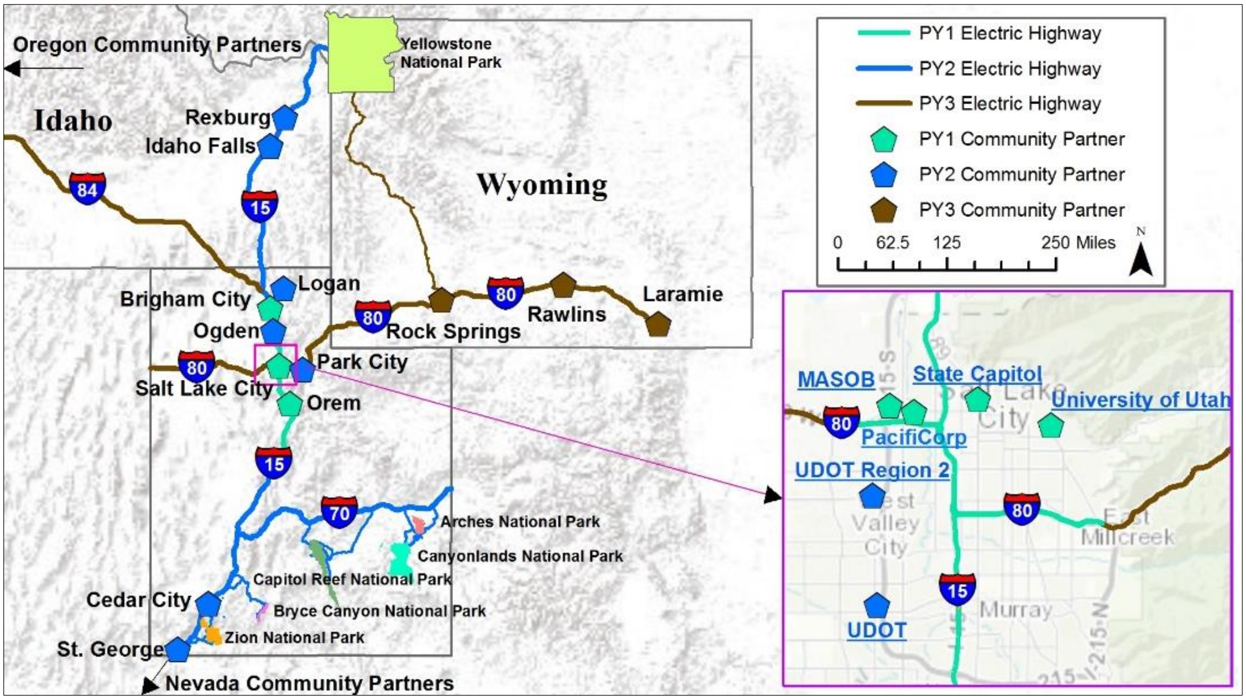

Figure 1. WestSmart EV Three-year Project Implementation Plan

The three annual phases for all project tasks include the following:

- Project Year 1 (PY1): Pilot year for initial implementation and initiation of data collection
- Project Year 2 (PY2): Expansion year for ramping up efforts and beginning strategic flow of data results back into project components
- Project Year 3 (PY3): Rollout year to reach full project capacity and incorporate lessons learned while disseminating best practice. The phased approach to building PEV growth through the WestSmart EV project includes 6 major tasks, as depicted in Figure 1. They include (1) developing over 1,500 miles of electric highway corridors along I-15, I-80, and I-70 in Utah, Idaho, and Wyoming; (2) advancing Workplace Charging within the corridors; (3) targeting fleet operators and incentivizing conversion of fleet vehicles to PEVs within the corridors; (4) building community partnerships and incorporating Smart Mobility programs to align efforts with long-term transportation planning; (5) collecting, processing, and applying data from across all activities through the WestSmart EV Central task to inform project reporting, develop new tools for utility integration of charging infrastructure, and detail lessons learned and best practices, and (6) coordinating outreach, education and dissemination of best practices through a series of workshops across seven states, and one-on-one meetings with business leaders though community partners.

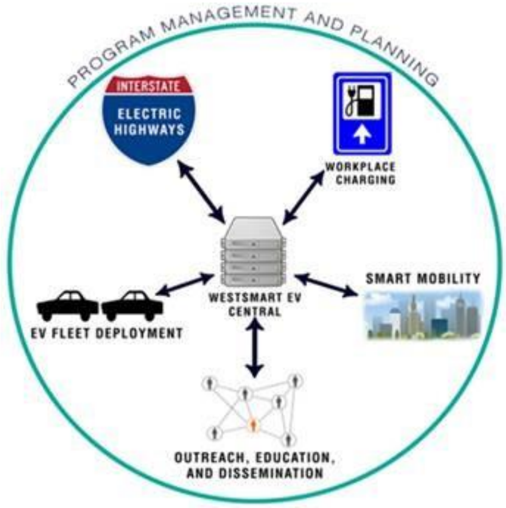

Figure 2. WestSmart EV Major Task Diagram

Task 1 - Electric Highways

WestSmart EV (WSEV) will electrify interstate highways in three states, with at least 65 DC fast chargers every 50-100 miles along the corridors and AC level 2 (L2) chargers covering every major community across the region. The project will create two primary electric interstate highway corridors along I-15 and I-80. In addition, the project will include portions of I-70 running east from I-15 in southern Utah to the Colorado border, I-15 from Utah to western Idaho, along with off-corridor highways leading to the national parks.

Task 2 - Workplace Charging

With the strong support of local air quality managers, municipalities, state agencies, business groups, and public interest advocates, WestSmart EV will aggressively push workplace charging through a combination of public events, workshops, and awareness campaigns. The project will incentivize installation of over 600 AC L2 chargers at workplace locations.

Task 3 – EV Fleet Deployment

The program will strategically target fleet operators with incentives to convert fleets to PEVs. All vehicles will use data loggers that enable data sharing and development of lessons learned and best practices. In all, the program will incentivize the purchase of over 200 PEVs.

Task 4 – Smart Mobility

WestSmart EV will pilot, expand, and roll out innovative concepts for zero local emission smart mobility in urban living along the Wasatch Front (a 100-mile segment of the I-15 corridor running north and south of Salt Lake City) and at university campuses throughout the region. This task focuses on eliminating the need for personal vehicles and providing all-electric solutions in the first-mile and last-mile trips for commuters. The lead pilot program in Park City will include electric buses (ebuses), electric bikes (ebikes), and an EV ride hailing program with 200 EV conversations between mobility service drivers and potential EV owners.

Task 5 – WestSmart EV Central

This task involves centralized data collection, analysis, modeling, and tool development, to inform investment and policy decisions. INL will lead efforts on data collection for vehicles and chargers; USU will lead the collection of behavioral data; and UU will lead the collection of utility infrastructure data.

Task 6 – Outreach, Education, and Lessons Learned

In this task, partners develop education and outreach materials, including a website, and conduct workshops throughout seven western states. Lastly, a PEV adoption model will be developed to ascertain effectiveness of the program.

Results

Task 1 - Electric Highways Results:

- The team successfully installed 79 DCFCs across the project territory surpassing the target of 65. Data collected from chargers indicated that the DCFCs have created an effective EV highway corridor (See Figure 3). Due to supply chain issues created by the coronavirus, the team was unable to complete DCFC installations in the state of Wyoming within the project timeline. The DC Fast Chargers were installed in the following communities:
    - Two in Garden City, Utah
    - Four in Lindon, Utah
    - Twenty-Two in Salt Lake City, Utah
    - Two in Castle Dale, Utah
    - Two in Bluff, Utah
    - Two in Richfield, Utah
    - Two in Taylorsville, Utah
    - Five in Sandy, Utah
    - Two in Herriman, Utah
    - One in West Jordan City, Utah
    - Nine at Park City, Utah
    - Three in Layton, Utah
    - Three in Summit County, Utah
    - Four in Logan, Utah
    - Two in Ogden, Utah
    - Two in Tooele, Utah
    - One in Draper, Utah
    - One in Orem, Utah
    - One in Eagle Mountain, Utah
    - One in Santaquin, Utah
    - One in Filmore, Utah
    - One in Cedar City, UT
    - One in Washington City, Utah
    - One in Price, Utah
    - One in Moab, Utah
    - One in Lava Hot Springs, Idaho
    - One in Shelley, Idaho
    - One in Rexburg, Idaho

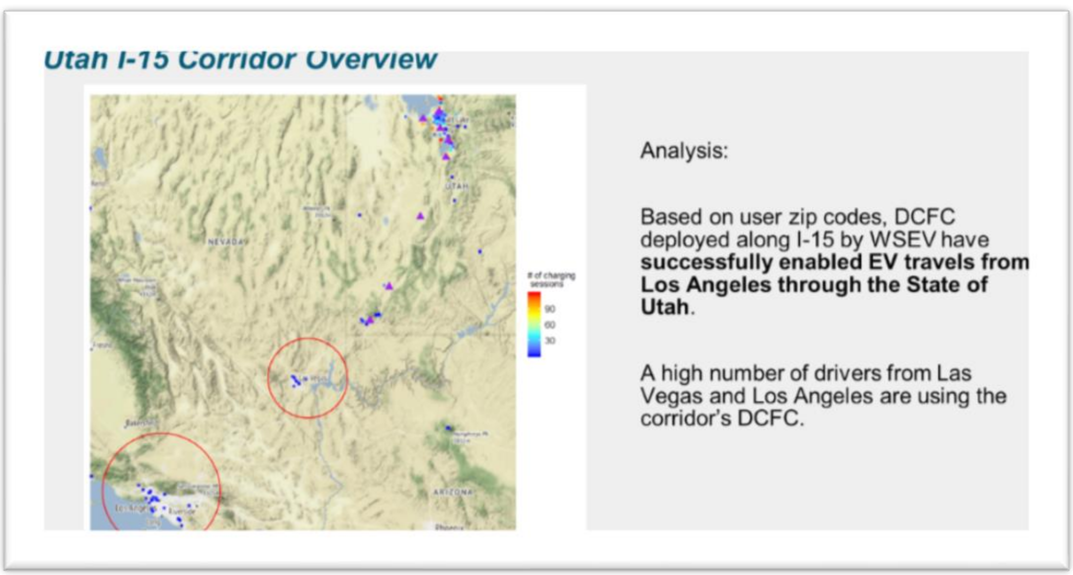

Figure 3 WestSmart EV Highway Corridor

Task 2 - Workplace Charging Results:

- An aggressive workplace charging program was implemented, focused on deploying Level 2 chargers (L2) primarily in the greater Salt Lake City area. As a result, 1,953 L2 chargers were installed as part of the program. In addition, a workplace charging case study was conducted at Packsize LLC, a technology company developing packaging solutions located in Salt Lake City. The Packsize corporate building has over 50 Level 2 chargers with a third of all employees owning a PEV. The case study evaluated workplace charging patterns and their impact on the grid. In order to measure the EV charger utilization efficiency a sparrow factor was used, defined as the ratio of time spent charging (t_{on}) to time spent connected (t_{total}). The team found that most PEVs used the workplace as their primary location for charging. There was peak charging between 7-10 am with most charging completed by 2pm. This charging profile fell outside of the utility's summer system peak of between 3-8 pm. As a result, workplace charging is a preferred mode of charging for utilities. The charging profile can be found in Figure 4.

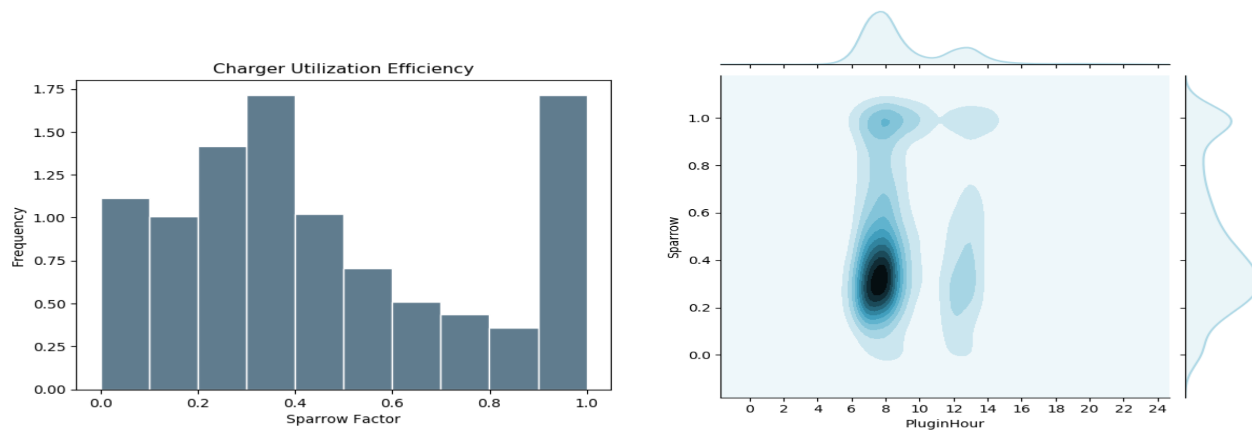

Figure 4. Workplace Case Study Charging Profile

Task 3 – EV Fleet Deployment Results:

- The project achieved 246 EV fleet deployments exceeding the target of 200 vehicles. Although the task was achieved it was a challenge to get fleets to transition to PEVs. Most commercial fleets utilize trucks and the lack of available truck PEVs made it hard for fleets to transition even with incentives. The most successful component of the fleet deployment program was combining utility incentives with vehicle manufacturer incentives,

Task 4 – Smart Mobility Results:

Electric buses

- The project successfully deployed six electric buses in Park City, Utah. The electric buses operated continuously and created one of the most traveled electric bus routes in the Country. The original batch of six buses were charged by 2-500 KW on-route overhead chargers. The project then deployed an additional nine electric buses, but these buses were charged by 60 KW depot chargers. The team conducted numerical studies evaluating the energy cost of buses and comparing on-route charging verses depot charging. The analysis, see Figure 5, found that the upfront battery costs (larger batteries are needed for depot charging) outweigh the higher operating costs from on-route chargers (smaller battery buses) with higher demand fees. The analysis also found that once battery prices drop, depot charging with larger batteries will be economical.

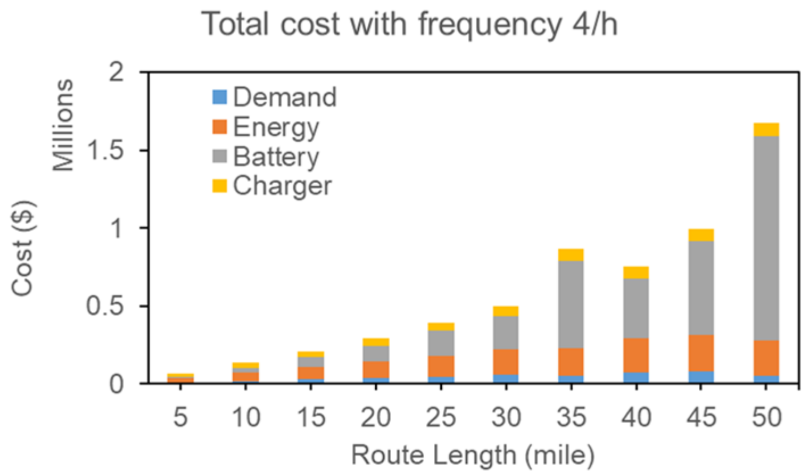

Figure 5. Analysis of Electric Bus Costs

- The project also experimented with co-locating chargers to share infrastructure. At one of the electric bus 500 KW overhead charger locations, the project deployed two 50 KW DCFCs while utilizing the same transformer. The new chargers were intended to be used by passenger vehicles. The co-locating of the chargers was quite successful and lowered the overall costs.

- Based on what the team learned in the Park City deployment, the project successfully deployed 5 electric buses in Salt Lake City with a plan to expand that number to a hundred electric buses.

Transportation Network Company (TNC) Program

- Launched the EV ride hailing program with Lyft, supported by Forth Mobility and achieved the goal of having over 200 EV conversations by drivers with potential EV owners. The participating drivers provided information on TNC activities, including an App that can be downloaded that tracks the charging characteristics and telematics of the vehicle. The Team analyzed the telematics and energy data from the drivers (See Figure I.16.3) illustrating the need for public DCFCs.

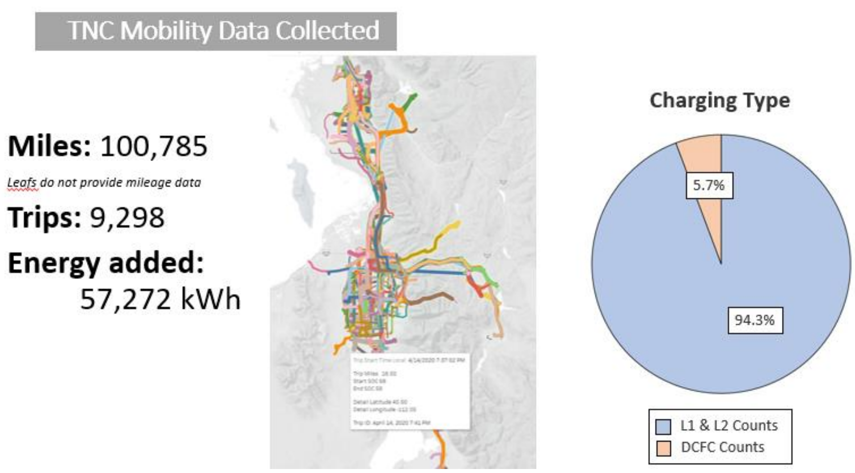

Figure 6 Ride Hailing Telematics and Energy Data

Task 5 – WestSmartEV Central Results:

- As part of this task utility integration with PEV chargers was evaluated. A residential model was developed to analyze utility transformer loading from the adoption of PEVs. The model employs typical utility data to construct a representative residential transformer load profile specific to the Salt Lake City area. Of particular interest was the impact of PEV loading on top of the existing residential loading as PEV penetration and charger capacity increase. The analysis evaluated two residential models: 1) 50kVA transformer, 11 homes; 2) 75kVA transformer, 15 homes. The models utilized a Monte Carlo probabilistic grid impact analysis tool. A flow chart of the analysis tool and the results from the model can be found in Figure 7. Results show that even at high residential EV charger integration, the utility transformer overload probability is trivial (0.7% for 6 chargers in 11 homes). Therefore, it is expected that existing utility infrastructure should be able to handle PEV adoption at levels of roughly 50%.

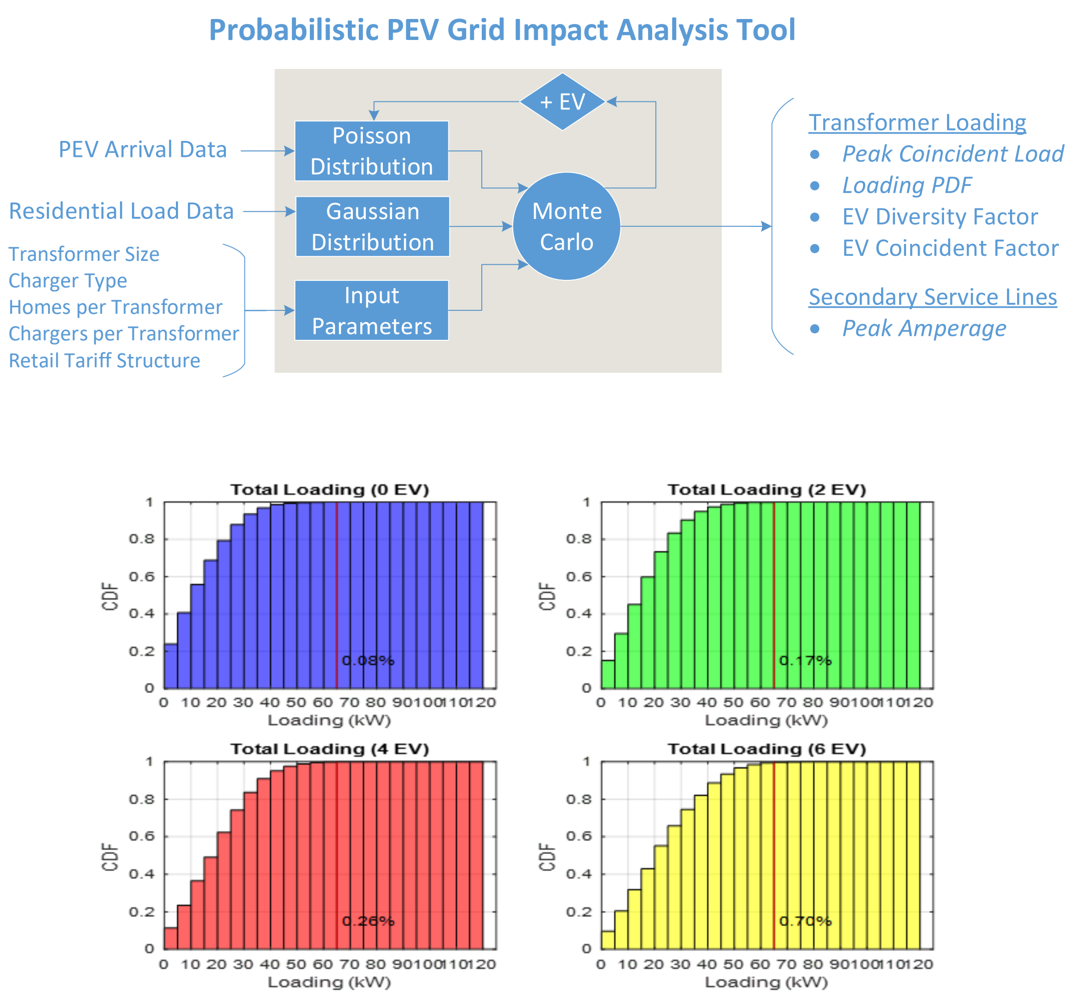

Figure 7 Residential Grid Impacts from PEVs

Task 6 – Outreach, Education and Lessons Learned Results:

- The team conducted multiple outreach and education workshops throughout the project's region.
- An awareness campaign with a website and social media communications was conducted.
- A detailed evaluation of best practices and lessons learned from the project was compiled and can be found in Appendix 1.
- Lastly, the team developed an PEV adoption model based on a Bass-Diffusion model. The Bass model forecasts, see Figure 8, that with the support from the WSEV program, the total PEV sales by 2026 will reach 56,870, which exceeds the impact goals proposed at the project's outset (i.e., the overall target impact of the program is to double the growth rate of PEVs in the region from 20% to 40% leading to more than 50,000 PEVs within 10 years). In addition, using the panel regression model combined with the Bass model, the PEV adoption under the hypothetical scenario without the WSEV program can be analyzed. Without WSEV, the predicted total PEV sales by 2026 would only be 34,475. The results demonstrate that, due to the deployment of chargers and other WSEV program and activities, the PEV adoption in Utah has been and will continue to be significantly accelerated. This is also seen by actual registrations in the state of Utah. According to the Utah DMV in 2017 at the start of the WSEV project there were 2,485 PEVs registered in Utah, by 2020 there were 12,522 PEVs registered in the state, roughly a 500% increase.

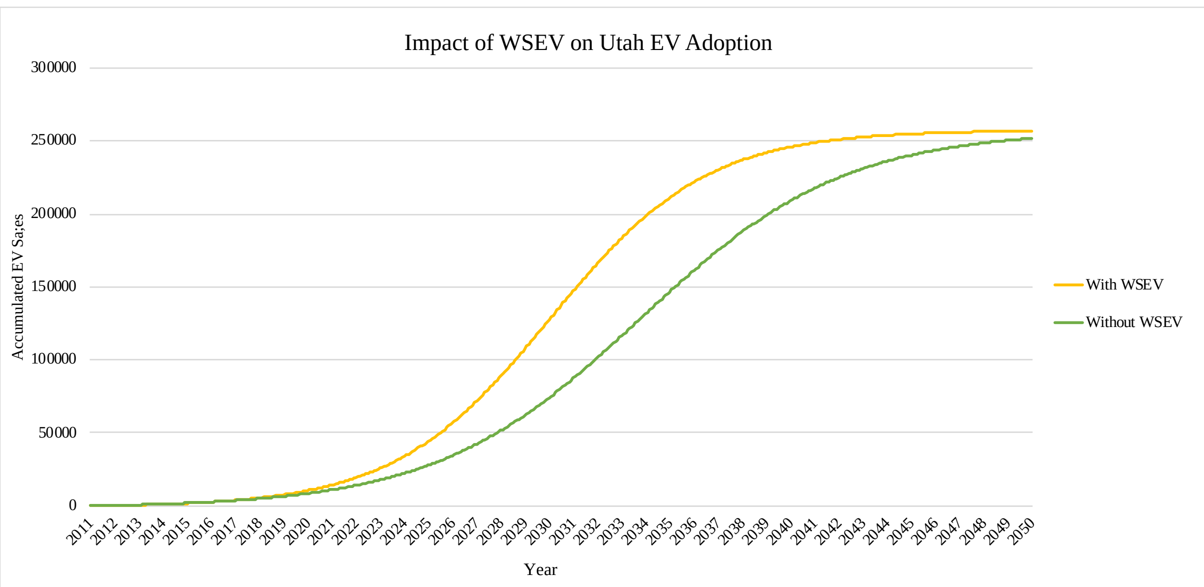

Figure 8. PEV Adoption Model in Utah

Conclusion

The WSEV project achieved all the project's goals including: the installation of 79 DCFCs across the project territory; installation of 1,953 L2 workplace chargers, 246 PEV fleet deployment, the development of Smart Mobility programs including the deployment of electric buses in multiple cities and a ride hailing program with telematics and energy data, and a comprehensive list of best practices and lessons learned. The project demonstrated that with a combination of community partnerships with strategic and effective programs PEV adoption can be increased. According to the Utah DMV in 2017 at the start of the WSEV project there were 2,485 PEVs registered, by 2020 there were 12,522 PEVs registered in the state, roughly a 500% increase.

Key Publications

Liu, Z and Song, Z. (2017). “Robust planning of dynamic wireless charging infrastructure for battery electric buses.” *Transportation Research Part C: Emerging Technologies*, vol. 83, 77-103.

Liu, Z., Song, Z., and He, Y. (2017) “Optimal deployment of dynamic wireless charging facilities for an electric bus system.” *Transportation Research Record: Journal of the Transportation Research Board, vol. 2647, 100-108.*

Palomino, A and Masood P. (2018). “Probabilistic Impact Analysis of Residential Electric Vehicle Charging on Distribution Transformers.” *2018 North American Power Symposium*

Liu, Z., and Song, Z. (2018) “Dynamic charging infrastructure deployment for plug-in hybrid electric trucks.” *Transportation Research Part C: Emerging Technologies, vol. 95, 748-772.*

Liu, Z., and Song, Z. (2018) “Network user equilibrium of battery electric vehicles considering flow-dependent electricity consumption.” *Transportation Research Part C: Emerging Technologies, vol. 95, 516-544.*

Liu, Z., Song, Z., and He, Y. (2018) “Planning of fast-charging stations for a battery electric bus system under energy consumption uncertainty.” *Transportation Research Record: Journal of the Transportation Research Board, DOI:10.1177/0361198118772953.*

He, Y., Song, Z., Liu, Z., and Sze, N. (2019) “Factors influencing electric bike share ridership: Analysis of Park City, Utah.” *Transportation Research Record: Journal of the Transportation Research Board, in press.*

Liu, Z., Song, Z., and He, Y. (2019) “Economic analysis of on-route fast charging for battery electric buses: A case study in Utah.” *Transportation Research Record: Journal of the Transportation Research Board, in press.*

Palomino, A., and Parvania M. (2019) “Advanced charging infrastructure for enabling electrified transportation.” *The Electricity Journal Vol 32, 21-26*

Palomino, A, and Parvania, M (2020) “Bayesian Hierarchical Model for Characterizing Electric Vehicle Charging Flexibility,” in *Proc. 2020 IEEE PES General Meeting,* Montreal, Canada.

Palomino, A, and Parvania, M, (2020) “Data-Driven Risk Analysis of Joint Electric Vehicle and Solar Operation in Distribution Networks,” *IEEE Open Access Journal of Power and Energy*, vol. 7, no. 1, pp. 141-150.

APPENDIX 1

West Smart EV – Program End Lessons Learned and Best Practices

PROGRAM END KEY OBSERVATIONS

Electric Highway Corridors

- Deployment and corridor build out success requires willing and resourceful site host partners, and site hosts can learn to maximize charging and minimize hogging in an effort to optimize benefit to both themselves and users.
- Existing utility capacity (and cost to site hosts of utility upgrade) is a key factor for placement of DC fast charging on interstate corridors.
- A significant stakeholder with vision, commitment and resources can catalyze and coordinate efforts among stakeholders as well as provide investment for charging needed to cover distances (road segments that may be less financially attractive to independent investment).
- EVSE location siting, particularly for DC fast charging, should be data driven with an investment to develop and maintain planning and optimization tools that can maximize benefit and minimize cost.
- Off grid remote EV fuel stations can be viable depending upon the demand profile and renewable (e.g., solar) energy availability; machine learning-based load prediction and solar energy availability prediction can significantly increase the profitability of potential remote EV stations; and dynamic pricing of electricity is an important component of remote (off-grid) profitability.
- Within the three project years, WSEV and its partnership can credit installation of more than 79 DC fast chargers and more than 1,957 Level 2 chargers

Workplace Charging

- Infrastructure buildout efforts benefit from finding and working with “championing” organizations and individuals (e.g., Packsize and Leaders for Clean Air in Salt Lake City).
- To influence EV adoption, it’s critical to get people into electric vehicles, and a good network of trusted dealerships can provide a variety of up to date EVs for potential users to experience.

Fleet Deployment

- Incentives (federal, state, and dealer) influence adoption at this point in the market’s maturity, in particular while vehicle cost continues to be an adoption barrier. Electric vehicle discount programs and incentives also remain essential to elevate awareness of the benefits of electric vehicles, which further influences increased adoption.
- Adoption among fleets increases with programs and information that help fleet operators see and structure decision making around total cost of ownership (TCO) and not just up-front costs.

Smart Mobility

- Increased EV adoption, particularly in early technology adoption periods, will require expanded public charging and reduced cost for DC fast charging.
- Keeping the cost of electricity and availability of charging stations accessible financially will help more drivers seriously consider transition to EVs.
- To overcome large capital investment barriers and promote effective adoption of electric buses, it is essential to develop cost-effective planning strategies to effectively reduce upfront and operational costs for BEB systems. Although an on-route fast-charging system, for example, requires higher cost for chargers, energy storage, and demand charges, it dramatically reduces the cost for on-board batteries, and its total cost can be ~50% less than overnight depot charging.
- Through novel renewable (e.g., solar) power generation strategies, utilities can manage EV charging and benefit from renewables’ potential flexibility to reduce loading and ramping requirements.

- E-bikes can effectively replace a significant number (up to 30%) of trips that otherwise may have been taken in a vehicle.

WestSmartEV Central

- To plan for the grid impact of residential EV charging, utility planners should consider system-wide permitting procedures as well as the uncertain nature of loading to define at what point is intervention needed to maintain reliability.
- EV charging demand at publicly sited charging infrastructure is dynamic, but presents predictable day-to-day utilization when generalized over a city-level scope.
- Network EV charging infrastructure data is ready and available to inform case specific risk and prediction models. Such data should be harnessed by power system operators to enhance the deployment and reliable operation of EV charging infrastructure.

Outreach

- Social media outlets for EV adoption have consistently grown with each platform filling a role, and consistent participation relating to the trending news is key to generating followers on each platform.
- Publicity and events can still make positive traditional news headlines toward EV adoption by leveraging the a champion organization's (e.g., public utility) relationships with the news, the newsworthiness of partner events, and the interest in local hot topics like clean air.
- Although messaging relating to the topic of adoption does not change significantly, style does, and the demand for fresh video content has become endless.
- A credible website with lasting effectiveness and lasting brand recognition works as a place to get "agreed upon" facts and information regarding EVs.

INTRODUCTION

The WestSmartEV (WSEV) project has accelerated adoption of plug-in electric vehicles (PEV) throughout the PacifiCorp/Rocky Mountain Power's (RMP) service territory in the intermountain west by developing a large-scale, sustainable PEV charging infrastructure network with coordinated PEV adoption programs. The project objectives have strategically deployed DC fast charging to create two primary electric interstate highway corridors along I-15 and I-80; incentivized installation of Level 2 AC chargers at workplace locations; incentivized the purchase of PEVs; provided all electric solutions for first-mile and last-mile trips, including electrified mobility service; provided centralized data collection, analysis, modeling, and tool development to inform investment and policy decisions; and developed education outreach materials and conducted workshops across the WSEV region.

The following sections describe efforts made, lessons learned and implications for resulting best practices for implementing similar programs in other regions.

DISCUSSION

3.1 Electric Highway Corridors

3.1.1 Efforts and Lessons Learned Summary

WSEV has "electrified" the I-15 and I-80 corridors with DC fast chargers and some supplemental L2 chargers. In years 1 and 2, some more "obvious" locations near travel-related retail areas along the corridor were easily identified, and chargers were installed with the help of established relationships with willing partners like Maverik and other local and regional site hosts. Site hosts also experienced a learning curve relative to users' charging and "hogging" tendencies relative to charger placement on site. As the first two years' proceeded, an additional valuable lesson learned for DCFC deployment that became clear was the need to consider existing utility capacity (and cost to site hosts of utility upgrade) as a key factor for placement of DCFC on interstate corridors.

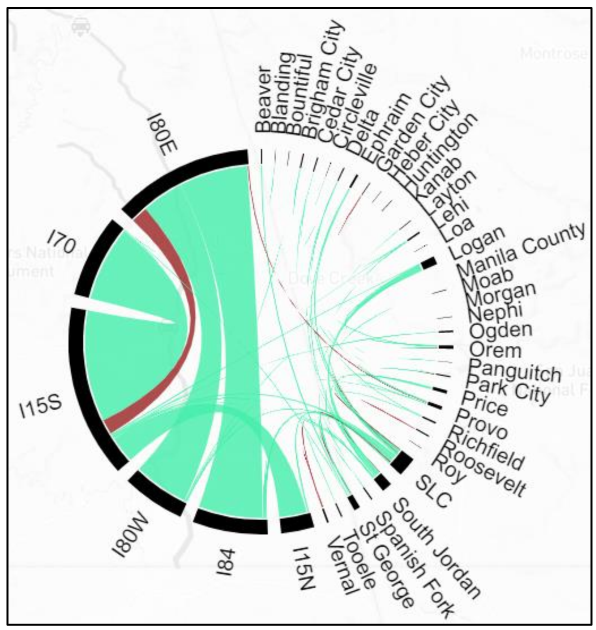

Figure 1. Trips possible in project year 3 following WSEV DCFC deployments.

By the beginning of year 3, virtually any EV trip was possible from point to point within Utah (Fig. 1), though some trips would have taken longer with DCFC still experiencing some coverage gaps due to extensive distances as well as potential locations with prohibitive utility upgrade costs. In the process of completing charging coverage on these key corridors through year 3, two additional lessons learned were gained while completing the task: 1) a significant stakeholder is required to engage and 2) data driven decision making can optimize placement.

To the first point, a significant stakeholder with vision, commitment and resources—in this case, Rocky Mountain Power—is required to both lead and coordinate efforts among stakeholders as well as provide investment for deployment outside of other independent operators where charging is required to cover distances but may be less financially attractive to independent investment. As that key stakeholder, Rocky Mountain Power filled any gaps with DCFC installation at the final key points along the target corridors. The net result, as can be seen in Section 3.6's Adoption Model update, the resulting charging coverage support current users and spurs deeper adoption.

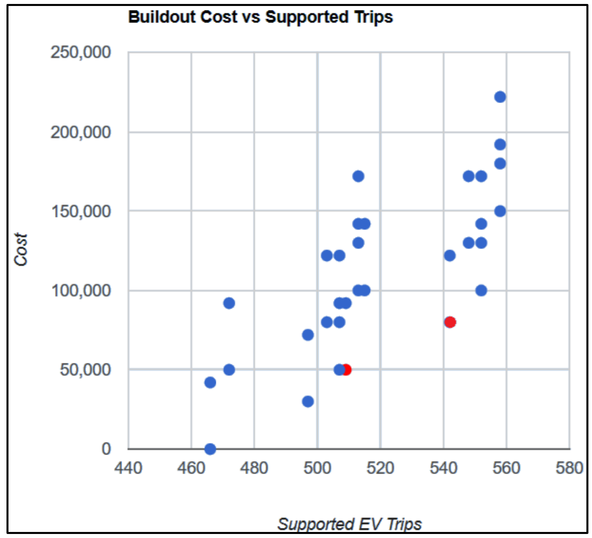

Figure 2. Siting optimization analysis plot indicating the best possible DCFC locations.

The second key lesson learned in year 3 is the value of a data-driven optimization strategy for charger placement. Early on in the program, Utah State University's corridor mapping model led to lessons learned that helped Maverik and other site hosts realize the benefits of DCFC investments through visualizing impacts relative to distances, utility capacity, current and anticipated EV adoption, vehicle traffic and potential customer flow. The resulting best practice of developing models and maps continued to inform site host identification as well as provide specific data that enabled partners to make informed decisions relative not only as to whether DCFC should be installed but also where, how many, and why in terms of potential energy, environmental, and economic impact. The optimization tool developed in years 2 and 3 demonstrated that out of millions of possible deployment scenarios only a few are optimal, in that they provide the most benefit for the least cost. Figure 2 shows an optimization analysis from year 2 with several possible buildout designs of five potential DCFC siting locations. Each potential site location was represented by a point on the graph and was evaluated by cost (y-axis) and benefit (number of EV trips enabled, x-axis). The two red dots represent the highest quality siting solutions. While the project could not provide ongoing maintenance funding for the optimization tool, its value was proven. The program end lesson learned is that if an organization is going to spend millions of dollars in infrastructure buildout, an investment in developing and maintain planning and optimization tools can maximize benefit and minimize cost.

3.1.2 Implications for Best Practices

The deployment of DCFC, and L2 as appropriate, along target corridors means that the vast majority of trips to and from key destinations (i.e., national parks and key business centers) through the road network in UT are possible with an EV. This is a significant outcome of the WSEV program. This outcome has been made possible because of three key best practices: 1) early and committed collaboration with key partners, 2) commitment and investment from a significant stakeholder, and 3) planning and optimization strategies and tools. Time and financial investments need to budgeted early for these practices with continual assessment and recommitment.

3.2 EV Fleet Deployment/Conversion

3.2.1 Efforts and Lessons Learned Summary

Salt Lake City EV Fleet Deployment / Conversion of Parking Enforcement

Salt Lake City was able to overcome cultural barriers to EV adoption through clear policy direction from elected officials, plus buy-in from senior Directors within the implementing City Department. Parking Enforcement staff were initially hesitant to accept the new EVs (Fig. 4), but they soon became the "preferred choice" among fleet vehicle options in that division once staff drove the cars and experienced the benefits. Staff using the EVs felt that the vehicles were fun to drive, highly convenient for their operations, and they also grew to appreciate the associated pollution reductions. Operationally, the vehicles have performed all the needed routes and daily operations without charging during the day (all charging is done overnight on Level 2 stations). The vehicles also performed very well during a warm July with outdoor temperatures consistently exceeding 90 degrees and the A/C used all day. The EVs in Parking Enforcement were averaging 90% energy savings (electricity vs. gasoline costs) relative to the previous gasoline fueled vehicles, after three-plus months of operations. The field supervisor also anticipates sizable and ongoing maintenance savings relative to the prior fleet vehicles. Overall, the initial integration of EVs into the Parking Enforcement fleet appears to be a major success and City staff expect EVs to become the new standard within their operations

Figure 3. Salt Lake City Parking Compliance Department Chevrolet Bolt.

From the City's perspective, Parking Enforcement and Facilities Management workgroups continue to support and enjoy using electric vehicles in their operations; however, the City continues to see as a barrier for Fleet Management considering lifetime cost of ownership versus upfront cost to purchase EVs, due to how city budgeting of Fleet is managed. There is a "split incentive" as the Fleet Division budget pays for the purchase of new vehicles, while individual departments and divisions realize the cost savings of decreased maintenance and fuel. For example, in year 3, the City added 32 BEVs, but disincentivizes the Fleet Management Department from adding more when it pays the higher initial EV cost, while other departments realize the total cost of ownership savings.

Despite realizing lessons learned from internal structure and operations, Salt Lake City has still experienced significant growth in infrastructure utilization during WSEV. Unique users of City stations grew from 1,315 to 1,953 in year 3 from 2018 to 2019. Free charging sessions at the City's 53 public stations more than doubled from 2017 to 2018 (12,870), and almost doubled again to 2019 (21,600). During the no-cost extension period, coincidentally primarily during Covid 19 containment (Apr-Jul 2020), charging sessions were down only 35% from 2019, and early (Jan-Feb 2020) charging sessions were 40% higher than the prior year. The City has actually announced enforcement of time limits (i.e., 2 to 4 hours) at EV charging stations due to increased usage. The charging session data shows that 20% of users are "hogging" and overstaying the posted time restrictions, which limits station availability to others. Salt Lake City did recently replace the only city-owned, publicly accessible DCFC stations on 500 South in the downtown area with two, dual output, Level 2 charging stations, due to ongoing high maintenance costs for the fast chargers.

Salt Lake City's Sustainability Department has also prepared an updated city code that will enhance EV-ready requirements for new, multi-family development. The Department will engage with stakeholders and developers in fall 2020 to discuss proposed EV-readiness requirements for new multi-family developments. Also in year 3, Salt Lake City Sustainability Department engaged internal City stakeholders on drafting a proposed “Electrified Transportation Resolution” which sets targets and gives direction to departments to work together to electrify internal fleet, work with external stakeholders to electrify public transportation, and develop infrastructure to incentivize public adoption of electric vehicle technology. This resolution has been proposed to the Mayor and the department expects to present to City Council in 2020. Salt Lake City continues to add clean vehicles to its fleet with 32 fully electric vehicles in its internal fleet and 259 hybrid vehicles, and it continues to offer free charging at all Level-2 publicly accessible parking stations. Salt Lake City installed eight new Level 2 charging ports in year 3 at Mountain Dell Golf Course, the Regional Athletic Complex and on-street parking on 500 South. These stations increase the total number of city-owned public EV charging ports to 38, plus 15 at the Salt Lake City Airport. WSEV has helped pay for ongoing station inspection and maintenance, cloud-based networking services, and phone support for Electric Vehicle owners. Finally, Salt Lake City developed and continues to host a website that discusses the City’s commitment to Electrified Transportation and resources, including charging station maps and links to incentives and partnerships and a dashboard that provides data on charging station use.

3.3 Smart Mobility

Program partners have facilitated programs to accelerate adoption of EVs, electric buses, and e-bikes through incentive programs and charging infrastructure development (including renewable power options). The programs’ objectives have been to accelerate sales of electric mobility options, to reduce emissions associated with gasoline powered cars, and to increase awareness of e-mobility through events, public outreach, and coordination with program partners.

Successful project aspects supporting e-mobility were also initiated later in the program that included car share and TNC EV integration as well as further utility optimization study.

3.3.1 Efforts and Lessons Learned Summary

3.3.1.1 Forth Program: Project Open Carshare Pilot

As another element of the WSEV smart mobility work, Rocky Mountain Power brought three partners into the fold for a small pilot project between three partners: Project Open, Forth and Envoy Technologies. The objective was to discover residents’ usage of two existing Nissan LEAFs (that the property owned) with a reservation tech platform. A goal was to have 10 regular drivers utilizing each vehicle, which was a number that would still allow the car to be considered an amenity. Unfortunately, the pilot never got past the initial beta testing due to COVID as well as other factors that delayed the launch described below.

Program Partners
Project Open is a community-based development project that seeks to bring attainable housing options to Salt Lake City. Their building is the first of its kind to be completely powered by the sun. Every parking stall is wired for charging stations, and there currently five charging spots available for residents to use. Though the building is located conveniently near transit stations, residents who don’t own their own vehicles still have a need to use them for appointments, trips to the grocery store and trips out of town. At the time of the pilot, Project Open had not yet conducted a transportation needs survey with its residents.

Envoy Technologies is a software platform that provides on-demand electric vehicles to building residents offering “mobility as an amenity.” This enables residents to have access to vehicles and reduce car ownership, which is less affordable in urban areas. Envoy was interested in finding out what the “right” pricing model would be for this community. The right price point would make the vehicles accessible for usage, but not so inexpensive that they were always booked, which would create complications if reservations ran over their designated time, etc.

Forth is a nonprofit organization that works to advance smart, electric and shared transportation. For this pilot project Forth was brought in to advise and support Project Open in launching the pilot through promotion and education.

Timeline & Launch

The project partners began discussing the design of the pilot in fall of 2019 with a goal of launching February, 2020. There were three primary things to put into place:

1. Install the Envoy technology in the cars so that when residents made a reservation through the platform, they could then unlock the cars with key fobs
2. Promote the pilot through the staff to Project Open's residents
3. Screen participants to ensure they were eligible to use the vehicles

While Envoy Technologies prepared their software, hardware installs and insurance coverage for the vehicles for the Giv Group, Forth created materials for outreach promotion to distribute directly to residents.

In February, the pilot team held a kickoff event at Project Open's Clubhouse; staff members participated and residents were invited to attend. There was an information session to learn about the free beta test period of the carshare launch, and one-on-one attention given to each resident who attended to assist them through the process of signing up. The vehicles were also made available for test drives with experts who knew the vehicles.

To qualify, residents needed a clean driving record and valid driver's license. The program was free for the first three months for beta participants. Once participants set up an account, they received $100/month in credit that didn't expire. The hope was to incentivize early adopters to test it out for free, provide feedback about their experience along the way, and promote it via word of mouth.

One couple that signed up shared a single car of their own and were excited to have another vehicle on hand for their use. Another couple who had signed up for the pilot didn't own a car, so were thrilled to have the option available to them.

Challenges & COVID-19

Before Launch

By offering carshare as an amenity, one of the key barriers of adoption had already been addressed -- the upfront cost. Charging logistics were addressed with the closed docking system -- charging stations for the vehicles in the parking garage.

That said, there wasn't any Project Open data from residents about their transportation needs conducted in advance or during the pilot. The pilot was embarked upon under assumptions that the carshare might add value through transportation alternatives and exposure to electric vehicles.

Because the LEAFs were 2016 models, their range was limited. In November, the Envoy software was installed and staff began using the vehicles before they were opened up to the residents. The staff found that if the cars sat for a long period of time, it'd pull the battery down. One car had a battery die after the Envoy Technology was installed, which was one delay to making the vehicle available.

There were also insurance complications that impeded a timely launch. By the time insurance technicalities were sorted out in March, COVID-19 became a concern and shortly after, all shared services were shut down at Project Open.

Through outreach to residents, staff attempted to direct residents to download the app prior to the launch event. This was not the case and it became evident that participants wanted to be assisted through the whole process and had many questions about the reservation system and the vehicles themselves. This may have been an indicator of a technology barrier for other residents.

After Launch

There were some tech challenges with the Envoy app where participants couldn't unlock the car, which then had to be towed back to the building twice. This ceased the main participants' interest in the carshare program.

Staff capacity to continue recruiting and supporting the participants was also very limited. Without continued promotion the pilot struggled to pick up momentum.

Usage Data

From the data below (Figs. 7 and 8) from Envoy Technologies, there were a total of 13 bookings recorded by one very active participant.

Figure 4. TNC bookings data.

Market: All | Program: Market Rate | Property Type: Multifamily | Management Co: All | Ownership Co: Giv Group | Branch Name: Project Open | Calendar: 3/27/2020 – 8/31/2020

Year	Booking Count	Avg per Car
2020	**13**	**15.56**
August	0	NaN
July	0	NaN
June	0	NaN
May	6	3.00
April	7	3.50
March	0	0.00
Total	**13**	**15.56**

Year	Distance	Avg Distance	Median Distance
2020	**196.04**	**15.08**	**9.08**
August	0.00		
July	0.00		
June	0.00		
May	44.27	7.38	7.61
April	151.76	21.68	15.00
March	0.00		
Total	**196.04**	**15.08**	**9.08**

Year	Minutes	Avg Minutes	Median Minutes
2020	**1,640.00**	**126.15**	**109.00**
August	0.00		
July	0.00		
June	0.00		
May	599.00	99.83	87.00
April	1,041.00	148.71	187.00
March	0.00		
Total	**1,640.00**	**126.15**	**109.00**

Year	Utilization per Vehicle	Car Count
2020	**0.36%**	**0.84**
August		0.00
July		0.00
June		0.00
May	0.67%	2.00
April	1.20%	2.00
March	0.00%	2.00
Total	**0.36%**	**0.84**

Year	Active Users	All Active Users	Registered Users	All Registered Users
2020	**1**	**1**	**3**	**3**
August	0	1	0	3
July	0	1	0	3
June	0	1	0	3
May	1	1	0	3
April	1	1	0	3
March	0		3	3
Total	**1**	**1**	**3**	**3**

Figure 5. TNC utilization data.

Open Share Lessons Learned

From a program design perspective, Project Open staff would need to have built in capacity and staff responsibility dedicated towards working on this. While Project Open staff were interested and willing to work on this pilot, it wasn't formally in anyone's job responsibilities, nor was there funding dedicated for it to be.

Project Open also communicated that in order to be effective moving forward, it would be helpful to have Forth come out to work with the staff in advance (rather than virtually) to provide technical assistance and co-create a design for the operations staff who would be managing the work on the ground. Additionally, this person would streamline communications between the participants, the residents, and Envoy if any issues were to arise. Giv Group had a point-person who wasn't handling the operations with the residents, so this would need to shift in a future iteration.

Since it was Envoy's first time being used solely as software as a service (SAAS), there were some complications, but they worked out the kinks with Giv Group and would like to work together again. There currently isn't another market alternative available.

3.3.1.2 Forth Program: Tracking Electric Vehicle TNC Drivers in Salt Lake City

This program has been a collaborative effort to track EV Lyft drivers in the Salt Lake City area between project partners Rocky Mountain Power, Forth, Utah State University, Lyft, and FlexCharging. With funding through the DOE and match from Rocky Mountain Power, this project's primary goal was to recruit and monitor electric TNC drivers to better understand their driving and charging habits and overall experience. The second goal of the project was to educate TNC drivers who might be interested in making the shift to EV. TNC drivers create a substantial impact on the environment, so focusing on transitioning vehicles on the platform as a means of reducing greenhouse gas emissions is an effective strategy. On average, electrifying a TNC vehicle is the equivalent of electrifying three single occupancy vehicles (Lyft, 2020). Additionally, The Union of Concerned Scientists found that TNC vehicles pollute 69% more than the rides they displace (UCS, 2020). Therefore, the electrification of TNCs has a substantial impact on GHG reduction (Alan, 2019).

This summary analyzes the information from the survey component of this project. Much of the information is qualitative and in written, testimonial form, and it highlights the driver perspective and patterns in the feedback collected over the course of nine consecutive months.

Project Partners
The local Lyft operations served as the lynchpin and active collaborator in ensuring that this work was possible by providing access to the drivers. This program work aligns with Lyft's electrification commitment to electrify all the vehicles on the platform by 2030.

Tesla and Nissan LEAF drivers downloaded the FlexCharging telematics app to monitor driving and charging patterns. Forth then directly engaged all the EV drivers in monthly surveys. A total of 17 individual electric vehicle Lyft drivers participated in both data tracking and surveys, though participation wasn't consistent. Telematics data was not available for several participants who drove Chevy Bolts, as FlexCharging software was not compatible with their vehicle model.

Effects of COVID
Forth and FlexCharging saw a significant drop off in the driving patterns of the drivers when COVID hit the US in mid-March. Demand on the app drastically went down, and some of the drivers who continued driving tended to have passengers who were essential workers. Uber reported that rides were down as much as 70% in cities hardest hit by COVID[1]. As of October 2020, rideshare demand remains significantly lower compared to 2019 and prior years. In response, many drivers have pivoted to the delivery service area of the gig economy. A decision was made to end the survey distribution a few months into COVID as ridership and eVMT were still low. More insights on COVID impacts to the participating drivers are included below.

Methodology & Design
Lyft agreed to provide direct access to their sample of EV drivers who opted-into this program. They had 30 area drivers in BEVs using the platform at the time of this program, which is a small sample size to begin with. In total, about two-thirds of the total all-electric drivers in Salt Lake City opted-into this project. However, some of this group were driving in older vehicles, which weren't compatible with FlexCharging, and other drivers didn't meet the five-ride Lyft minimum per month, which isn't unusual for rideshare driving.

Monthly surveys were administered directly to the drivers and 61 total surveys were completed. The surveys for the most part included the same question set, though some questions were added or revised over time. For example, after significant changes in circumstances due to the COVID-19 pandemic, Forth adjusted the surveys in the final few months to address the new climate drivers were working in.

Because a sample of 17 drivers is not large enough to draw broad conclusions, trends in the information we received are discussed here. Forth works with TNC drivers in other electrification programs, so, where possible, this report identifies what driver feedback mirrors feedback in other similar work.

Driver Participation
Some drivers were more consistent than others with participating in surveys. There is a segment of drivers who only participated in the program launch's first survey. Others were far more consistent and thorough with feedback. Another hurdle with participation was the process of downloading the FlexCharging app. Forth has engaged with drivers as part of its program work broadly and has found that drivers' busy schedules challenge full participation in program efforts.

Some driver's inconsistent involvement is partly reflective of the fluctuations in drivers' actual time on this job. Lyft confirmed driver eligibility by cross-checking that drivers completed at least five rides a month on their app. There were instances where some drivers did not meet this requirement for participation in further surveys. One outlier appeared to have moved across the country. Changes in app use and work circumstances is a typical feature of the gig economy.

Results & Trends
Vehicle and App Use
All drivers stayed in the same vehicle through the duration of the 9-month survey component of the program. Seven of the 17 total drivers reported that they shared their electric vehicle with another driver. One driver shared their vehicle with a spouse--who also used the vehicle for rideshare work. This pair installed solar panels on their home to support buying an EV and were very happy with the sustainability and cost savings factors.

It is common for rideshare drivers to "diversify" in the gig economy and drive for several rideshare and delivery apps. This was especially pronounced as drivers adapted to COVID-19. Eleven total drivers reported driving for another gig in March, April and May. One driver who had been strictly a Lyft-only driver reported

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[1] Uber says rides down by as much as 70% in cities hardest hit by coronavirus, looks at delivering meds https://techcrunch.com/2020/03/19/uber-coronavirus-update/

driving for another app in the month of March. One driver shifted away from rideshare altogether in May. Another driver reported staying with rideshare minimally, with only 20% of their driving work being for rideshare now. Four respondents stuck it out and all of their driving work remained entirely for rideshare services.

Health concerns around COVID-19 caused some drivers to avoid working with passengers altogether for the time being, though, optimistically, every participating survey respondent in March, April, and May reported that they plan to continue rideshare work into the future as the situation improves. Drivers also reported an increase in demand in May compared to April.

Salt Lake City Market

There are some characteristics of the Salt Lake City rideshare market that make it unique in its electrification efforts. The high-demand season is in the winter because of ski season. This makes the airport an important hub during this time, as well as the routes up to the slopes. Utah is not a ZEV state, so new and used EVs aren't readily available at dealerships. A strong majority of the current EV drivers have access to at-home charging, which differs from other urban markets. The demographics of this region could also impact transportation needs—for example, vehicle size and locations for pick-up and drop-off.

Lyft has collected information from drivers and riders in the Salt Lake City area. They report that 94% of the area drivers drive fewer than 20 hours per week; most drivers are very part-time or even active only at certain times of the year or for events. 36% of Salt Lake City riders use Lyft to get around when public transportation does not operate. Also, 34% of area rides start or end in low-income areas. Rideshare services those who do not have a vehicle, with 48% of area riders who do not have access to a personal vehicle reporting that they would be more likely to purchase a vehicle if services like Lyft became unavailable (Lyft – Economic, 2020).

Driver Experiences

Vehicle Performance and Testimonials

Forth received many positive testimonials through the monthly questionnaires. The top benefit to drivers most consistently stated were "cost savings," "performance," and the handling and design of the vehicle. A secondary but common point of enthusiasm among the drivers is the environmental benefits. Figure 9 is a word cloud produced representing their feedback.

Figure 6. Word cloud representing TNC driver experience.

Some participants clearly described their experience as better than working with a gas vehicle. There were positive mentions about the smoothness of the ride, acceleration, regenerative braking, and how safe and quiet their car is. Cost savings came up the most often as shown in Figure 10.

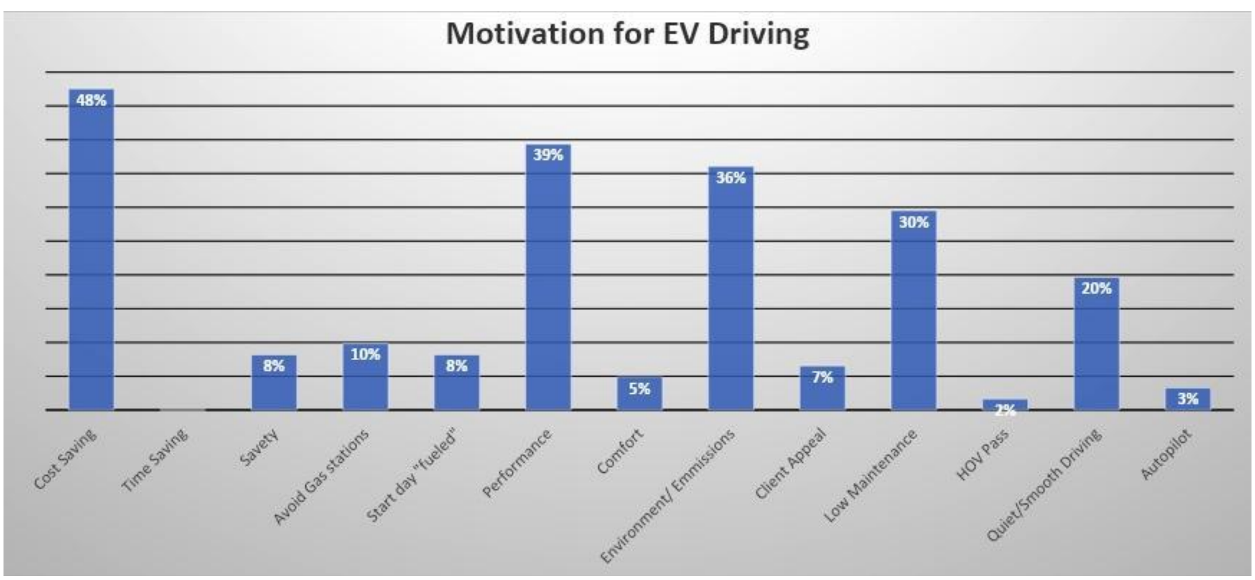


Figure 7. TNC EV drivers' survey responses about motivation for EV driving.
Following is a selection of participant testimonials:

- *"Driving electric is the future and it doesn't slow me down or affect my income."*

- *"Going electric is the most seamless easy transition you'll ever make."*
- *"I love driving rideshare with my electric vehicle. It's where I can make more money."*
- *"Electric rideshare can be a safe and clean way to earn money."*
- *"Due to fuel & maintenance costs, I feel doing rideshare with an EV is worthwhile."*
- *"The cost savings of charging free makes Lyft incredibly worth it."*
- *"Electric vehicles are the cleanest and most efficient way to earn money."*
- *"The clean air we have seen with reduced traffic shows how much internal combustion engines contribute to air pollution. Electric vehicles are a way to improve air quality and provide excellent transportation. They are also an ideal way to earn money as a driver."*
- *"I'll never go back to a gas car, you will save so much $ over time with an EV, build your credit score, build up a down payment, and get a Tesla ASAP."*
- *"Driving an electric vehicle for rideshare is awesome! People love the experience and I love not paying for gas and oil changes."*
- *"Switching to an electric car has changed many facets of my professional and personal life for the better. Besides the high entry price tag, I do not see any downsides to owning an electric vehicle."*
- *"Compared to gas cars, you can easily make the car payment for a long range tesla doing lyft/uber in 3 day if you are driving full time. Especially if you mainly charge at home, you will spend next to nothing on electricity so everything you make is pure profit. Compared to cheaper electric vehicles, you are going to make a lot more money because you can drive for a log longer before needing to charge again and can fast charge while you eat lunch if you have to."*
- *"I drive 3 times more now and spend less than a quarter of what I used to spend on electricity vs gas."*
- *"I love the smooth ride and regenerative braking."*
- *"It's quiet and peaceful because there is no engine. Also the peace of mind for not polluting the air."*
- *"It's how driving was always meant to be. I love that I never have to go to gas stations."*
- *"Our family has saved so much money."*
- *"Always start each day with a full "tank". Passengers love them. So fun to drive. 1/5 the cost of gas."*
- *"Better ride, better safety, lower operating costs, better performance than ICE vehicle."*
- *"It's great to help the environment and my pocketbook at the same time."*
- *"I love not paying for gas and not worrying about emissions. Also the maintenance on my car is fabulous."*
- *"Low-maintenance, relatively cheap charging cost. Guilt-free driving."*
- *"Low maintenance, fun and comfortable ride."*
- *"I love the smooth, easy way that EV's handle and feel on the road. Being able to drive guilt free is a HUGE benefit. It has enabled me to meet new people and open up new avenues of dialog regarding the environment and the municipal push for clean air."*
- *"Don't need to stop for gas every other day, saving a lot of money."*
- *"Electric is very fun to drive with the instant power, zero maintenance and quiet ride."*

Adapting to COVID

The COVID-19 pandemic has greatly impacted the TNC industry. Forth modified surveys to gain insight about these issues from drivers on the ground. In April, Forth added a survey question to specifically ask drivers what destinations became most common with the shift in circumstances due to the lockdown. Grocery stores, hospitals, banks, workplaces, and residences were most frequently listed. Drivers noted that they were transporting essential workers.

Forth also asked what drivers have done to adapt to COVID-19. Safety precautions that were mentioned were wearing a mask, gloves, and PPE; offering riders hand sanitizer; sanitizing their car; driving less; and shifting to delivery work.

Forth also asked a more pressing question: *What are your needs, questions and challenges at this time?* Answers included that they wonder if demand will pick back up, and if the work is safe even with a mask. Decrease in demand was a clear challenge. They hoped their passengers were clean and safe. One driver mentioned they don't have as much energy--these circumstances are certainly exhausting for many. Another driver reported that riders were having a variance in wait times that corresponded with drivers available at different times, and that there wasn't consistency with supply/demand. Another response said that riders aren't comfortable going out and about.

Staying on top of social distancing and keeping things clean is an added, ongoing challenge (and expense). Many drivers are competing in the food delivery space. Some drivers expressed uncertainty of the future of rideshare and the long-term impacts of COVID-19, though each driver replied that they are interested in continuing rideshare work as things improve.

Charging and Range
Most drivers in this program spend $20-40 to charge every month (Fig. 11). There was clearly one driver who works full-time and does not have access to charging at home, and therefore reliant on public fast-charging. They stood apart in their responses of consistent high-mileage driving paired with spending over $100 per month on charging. For reference to ICE vehicles, Forth has learned from drivers that spending $20 in gas each day as a full time, high-mileage driver is not uncommon. Spending over $100 each month on fast charging is characteristic of a full-time driver that depends on public infrastructure. As EV adoption rates increase on rideshare platforms, more charging stations are critical for this demographic of drivers.

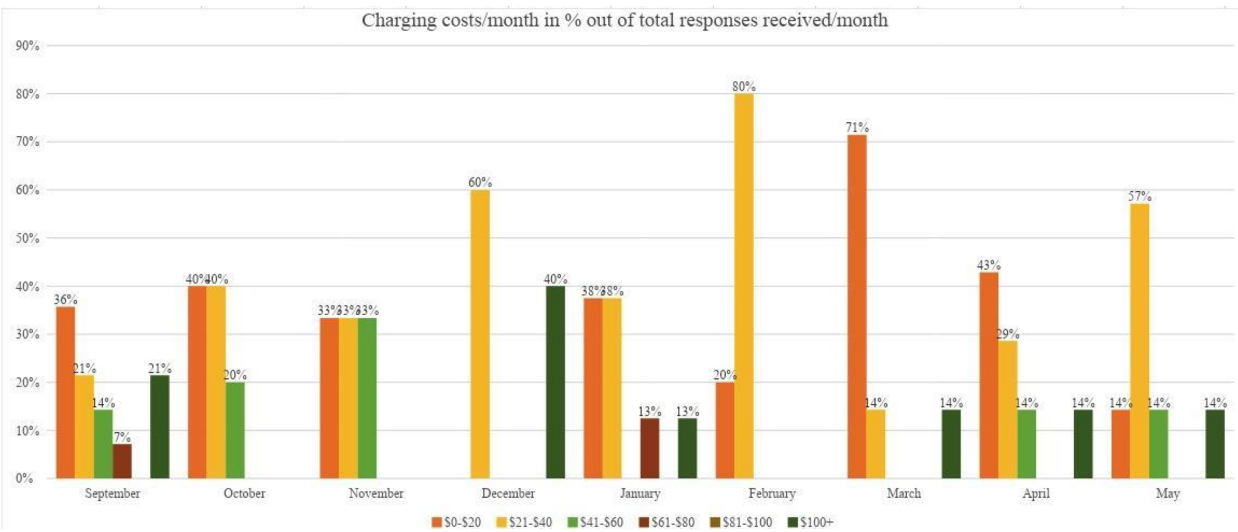


Figure 8. TNC EV drivers' charging cost data.
Nearly all of the participating drivers have access to at-home charging. Transitioning to an EV is easier for anyone who has access to charging at their residence, and especially nice for those who drive for work to start their day with a full charge. This aspect of our sample shows that the participant's circumstances are that of many "early adopters": early EV adopters tend to have tools, including charging options, alongside the research to facilitate their decision to make the switch.

Regardless of whether someone has at-home charging, for people who drive for work, it's important to know of public options. We asked drivers what they like to do while they charge. They responded (Fig. 12) with various activities: email and text, stream movies, listen to the radio, play games, read, surf the web/research, eat, walk, shop, rest, and sleep.

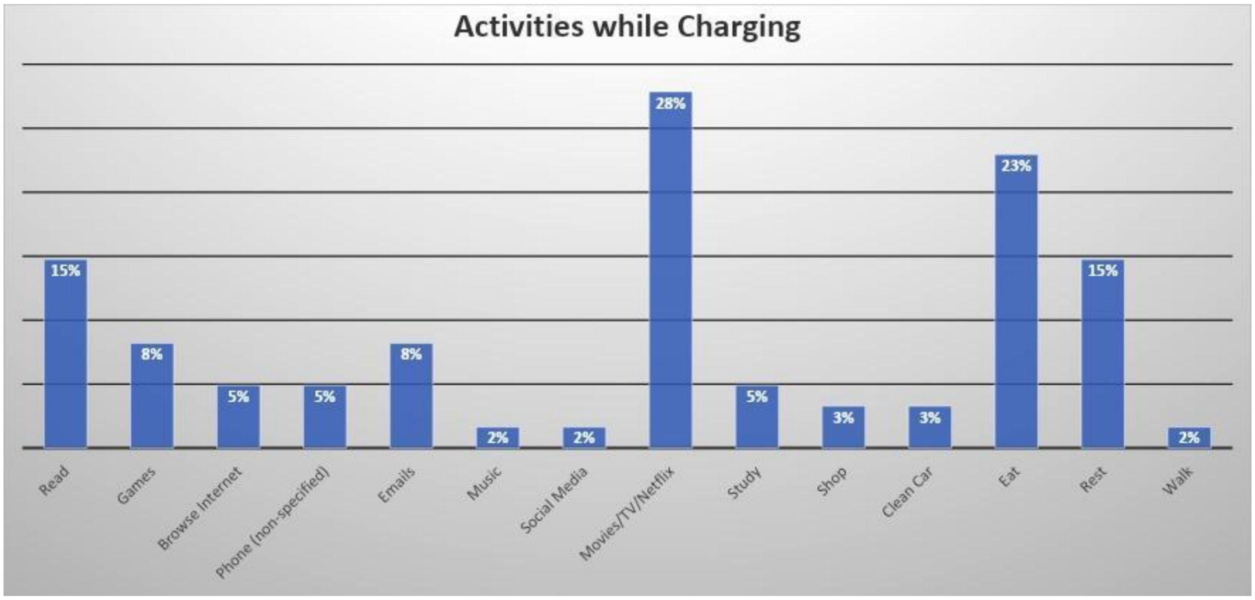


Figure 9. TNC EV drivers' activities while charging.

Forth was curious how drivers perceived their time spent charging as well. We asked if they saw this time as a time that decreases their ability to make money on the app because it's common for drivers to consider cost/benefit as "independent contractors" making ends meet. For the most part, drivers responded that they did *not* see time spent charging as time away from making money on the app. Some drivers did say yes, however, and one participant even went back and forth on their answer over several months.

Drivers who did not perceive charging as decreasing their ability to make money also participated in surveys more consistently in this sample. Further, for almost all of those who perceived charging time as time that decreases their ability to earn, the respondents were drivers with access to at-home charging. They likely view time resorting to public charging differently than those accustomed to using it regularly. There were additional drivers who, despite utilizing at-home charging, said that the opportunity cost of the time spent on charging did not decrease their ability to make money. This viewpoint could be due to the fact that electricity is cheaper than gas and drivers engage in other activities while charging.

A clear adaptation that EV rideshare drivers make is adjusting to their EV's range. Forth examined how careful drivers have to be in the Salt Lake City area to not run out of battery entirely. Forth asked: "At what range do you turn off the app to go to charge?" The typical range drivers indicated was between 25 and 50 miles. Those who cut it close mentioned 5, 7, 8, 9 and 10 miles remaining. The most frequent responses to this question were "30", "40" and "50." Around 30-50 miles is a common response both in this sample and in other markets.

Forth asked drivers about charging apps and providers they use. Percentages of apps participants mentioned are listed in Figure 13: Tesla superchargers and app, ChargePoint, Greenlots, Nissan Connect, Electrify America, EVgo, PlugShare and SemaConnect.

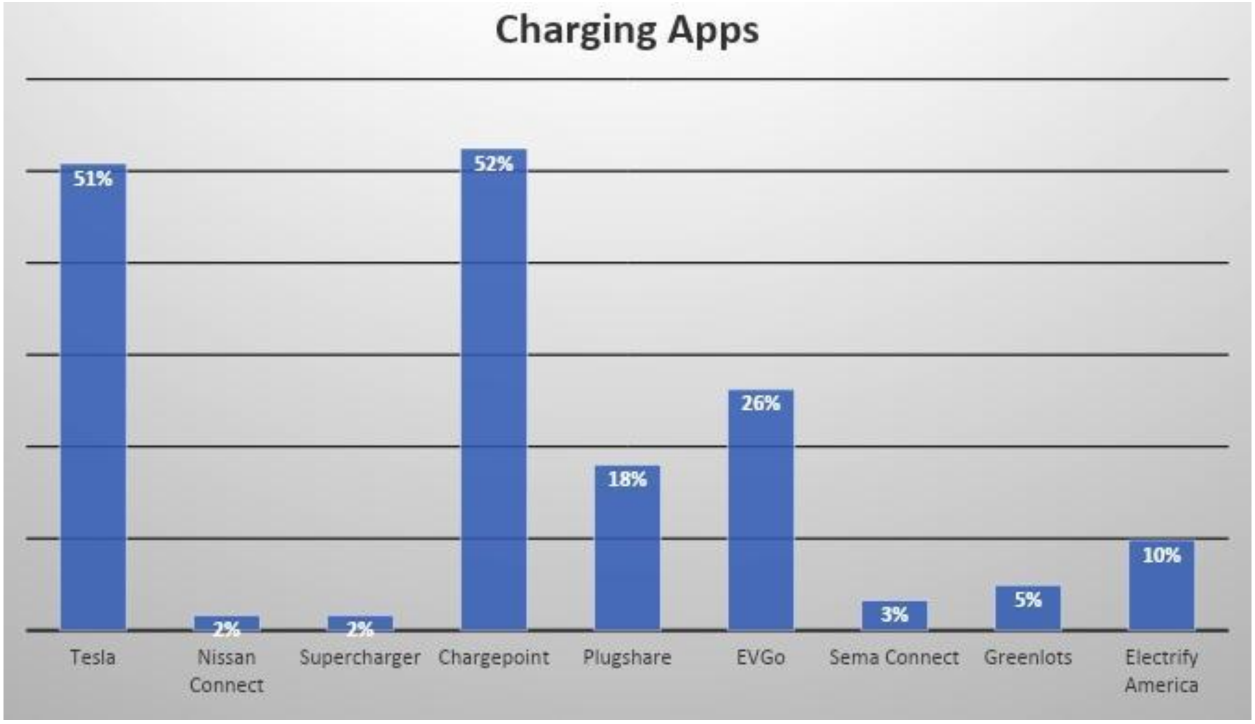


Figure 10. TNC EV drivers' charging app usage.

Drivers would like to see chargers installed (with **bold** signifying multiple drivers responses) in Park City, Provo, Ogden, along the freeway, North Salt Lake, South SLC, Heart of SLC, Sandy, South Jordan, West Jordan, West Valley, Holladay, Wendover, Farmington, Layton, Sugarhouse, Cottonwood Heights, Draper, Eagle Mountain (Ridley's) and Saratoga Springs (near Smith's.)

Forth asked about the kinds of areas that could be good options for more chargers. Specific location types that would be convenient for drivers include hotels, movie theatres, libraries, gas stations, grocery stores, at/near public transit hubs, and at office buildings.

At points during the project, certain chargers gave drivers trouble. Details of the exact chargers were hard to pin down, though the chargers that were mentioned include the following locations:

- Vernal
- Walgreens stations
- Ogden Nissan
- Greenlots (unspecified location)
- Various SLC chargers by Pioneer Park
- Nephi
- Tesla on State Street slow
- Sugarhouse next to Whole Foods
- 55 E 300 S Downtown SLC
- Airport parking lot
- Harmon's EVGo Downtown Salt Lake
- Problem stations: West Jordan

Rider Experiences in Ride-Hail Electric Vehicles

Forth received a substantial amount of positive feedback from drivers specifically about passengers' experiences riding in their EVs. Some words drivers used to describe the riders' reactions to EVs include *love, clean, interesting, good-looking, smooth, nice, cool, and awesome*.

Drivers report that riders have "positive curiosity" and "interest in the technology, affordability, and tax incentives." Passengers "wonder about range, charging styles and speed, cost of ownership and maintenance." Below are some driver testimonials about their riders:

- *"They love every minute of it and want to get one themselves."*
- *"The majority of my time driving is answering questions from passengers about electric vehicles. I feel it is a great advertisement for how functional and enjoyable they are."*
- *"They like how smooth the drive is, they love the idea of electric cars and it gives them an introduction to them. Most people have never driven in one and I get to answer some of their concerns."*
- *"People love the car. The tech, the feel, the experience, smoothness, quiet, no gas, etc."*
- *"People are generally thrilled with the car. Part is due to electric; mostly due to being a Tesla. They comment on the design & features the most."*
- *"They love it. Comments tend to be "it's a spaceship", "it's like riding in the future", etc."*

In conclusion, "love it" is a common response, which is consistent with Forth's work with TNC drivers in various markets. Drivers "ask a lot of questions about EVs" and the impression that a full-time driver has on area passengers is significant and positive. Forth also concludes that many people's first time in an EV could likely be with a rideshare driver.

Driver Recommendations
Main categories of advice or suggestions from drivers about operating an EV for rideshare work include charging availability, app functionality, and that they do indeed recommend electric vehicles for this work.

Drivers would be keen to see more charging stations (locations suggestions can be seen in Figure 14), and faster charging (see Fig. 15). As independent contractors, drivers tend to think about how costs add up. They often will go out of their way specifically for free charging. They also would love to see charging speed increase (less time on the road is less time making money).

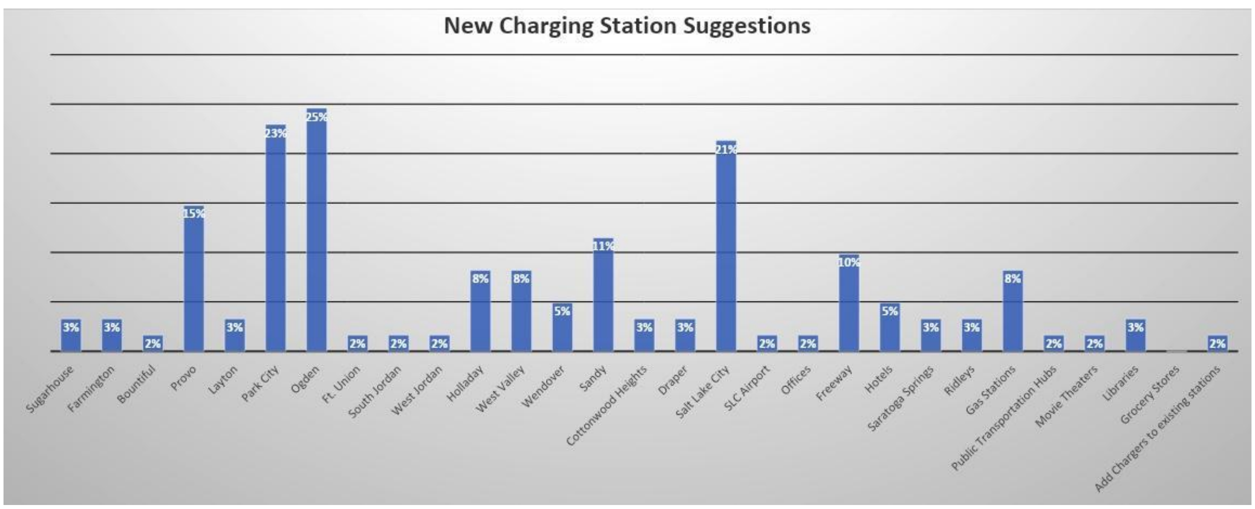


Figure 11. Salt Lake City TNC EV drivers' suggestions for new charging stations.

- *"Try not to go under 50 miles of range, you might get a ride from the airport going uphill to park city."*
- *"Patience and timing is key with electric charging."*
- *"Install seasonal tires."*
- *"EVs are a great way to go with rideshare, as long as you have decent range."*
- *"As long as you have good range, EV rideshare is top notch."*
- *"Electric is the way to go, local incentives make it worth it."*

- *"Driving electric is great, easy even, but requires a little planning to develop a routine for having enough range for the entire day."*
- *"The main reason I drive an electric car is the cost savings. However, driving EV presents some limitations with range."*

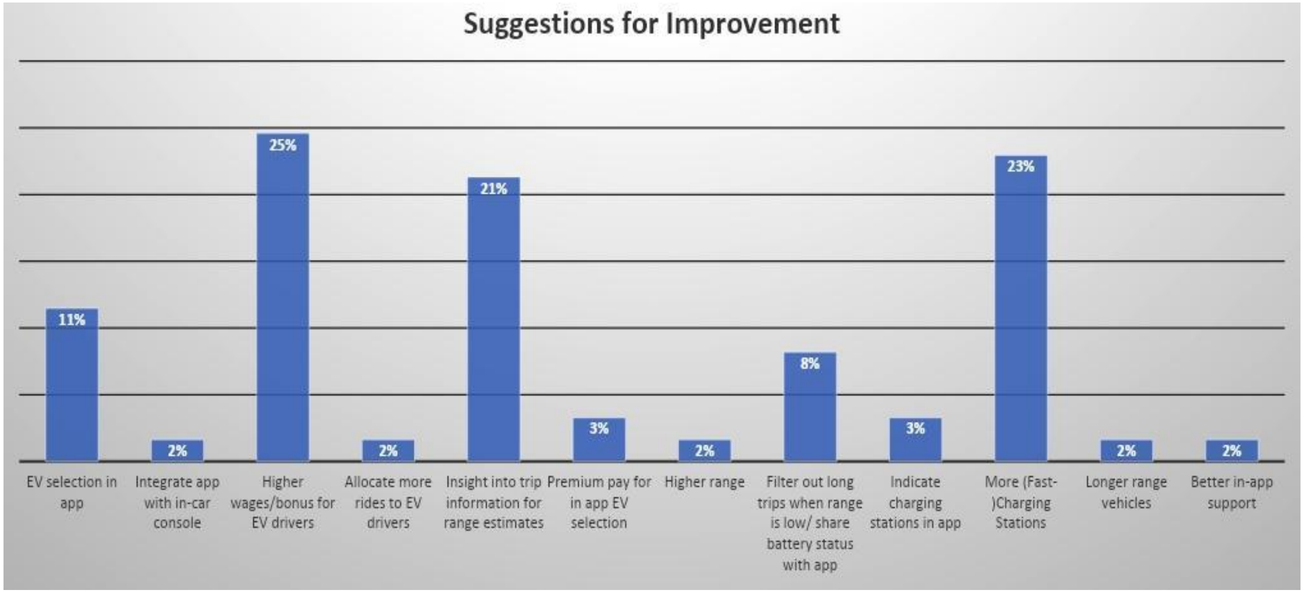


Figure 12. Salt Lake City TNC EV drivers' suggestions for charger improvements.

There was a lot of feedback about the Lyft app's functionality for EV drivers. There were some clear patterns in their experience with the software, and some pain points arose. Sometimes, they have to cancel rides through no fault of their own because they don't have enough charge to complete an assigned ride. So they would like to see the full trip information before accepting a ride to ensure they can successfully complete the request. One idea mentioned was to "integrate" and share their battery status with the app so that they would get rides appropriate for their BEV. There would have to be wiggle room in this calculation for the fact that geography and weather affect real-world range. Another "integration" opportunity suggested would be for the app to display charging stations.

It would also be ideal for an EV to be prioritized in the app algorithm for shorter trips, ideally avoiding freeways, as EVs get the most range maintenance while doing short city trips. This is conveniently the opposite of a gas car's performance as well since ICE vehicles are more efficient at higher maintained speeds.

Drivers would also like for there to be an option on the user side to "select electric." One driver mentioned that even passengers have requested this. Moreover, there were many mentions of an EV bonus or premium for the green rides they are providing. A premium to EV drivers could help motivate drivers to make the switch. Recently, Uber implemented Uber Green that includes an incentive of $1.50 for EV rides through September of 2021 as they strive to make their fleet all-electric in the US by 2030 (Gibbons, 2020). Lyft announced their goal of being all-electric by 2030 earlier in the year as well, but have yet to provide an incentive to drivers directly.

FlexCharging Tracking and Data

FlexCharging telematics tracking software was installed in nine cars that *also* were used by drivers who participated in surveys. Through this app, FlexCharging monitored driving and charging patterns of all participating Tesla and Nissan LEAF vehicles. Twelve total drivers signed up.

Figure 16 shows a brief, high-level discussion about findings from the FlexCharging component of this project. For full results, please see the full FlexCharging report.

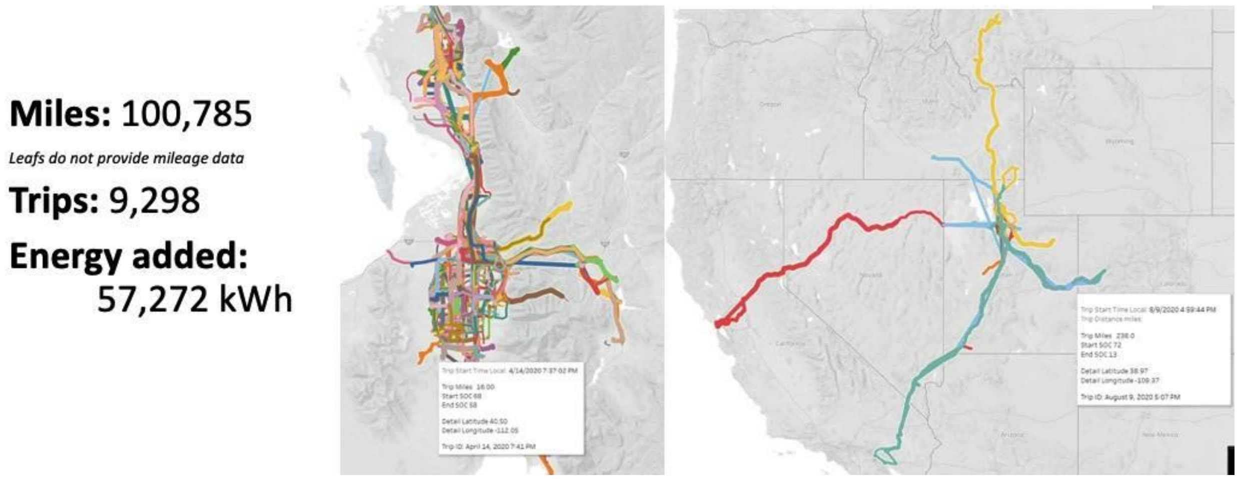


Figure 13. TNC EV drivers' miles and area covered.

The amount of miles tracked and area covered by these electric vehicles was substantial. The long distances riders travel demonstrate that the application of these vehicles is reaching parity with their ICE counterparts. There were examples of long-distance, out-of-state and multi-state trips that were recorded that imply that the personal use of the vehicle is important outside of the local rideshare work component for the drivers.

Figure 17 shows that driving patterns varied widely across individual drivers, even if they use vehicles with the same electric range. 80% of days driven are <100 miles but some drivers work longer days than others (those to the right of the red line.)

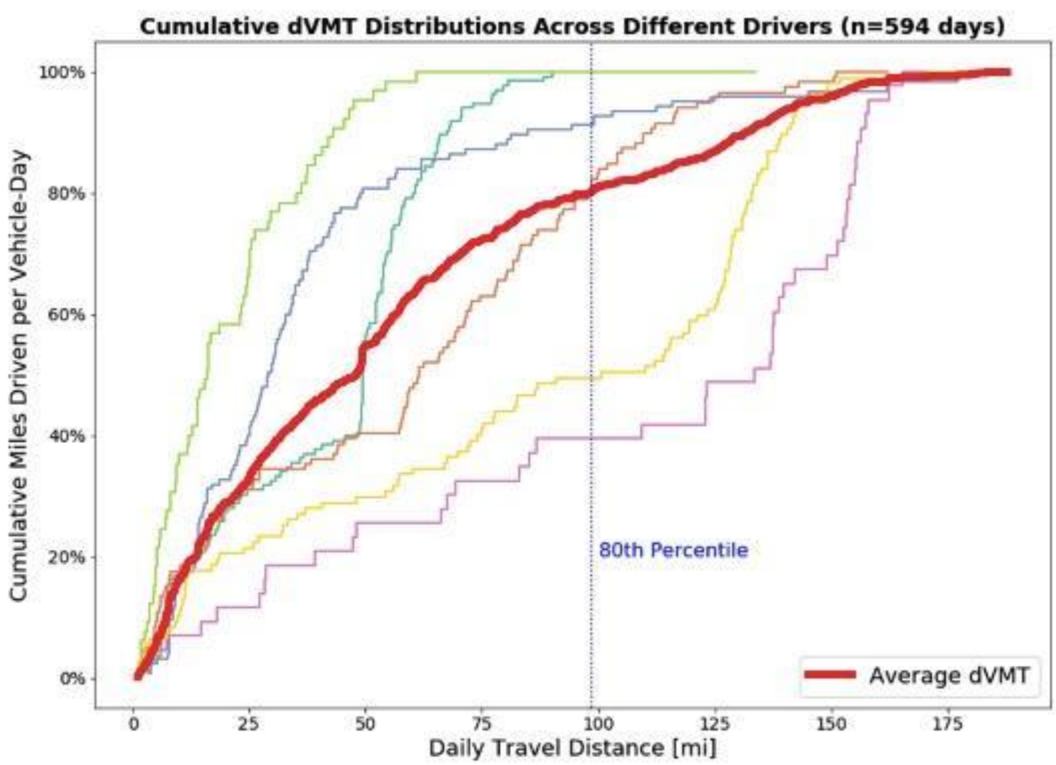
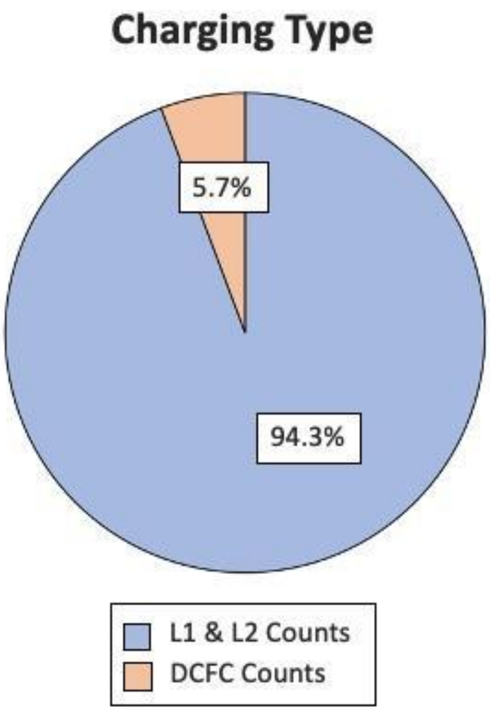


Figure 14. Varying driving patterns for TNC EV drivers.

As also found through Forth surveys, these drivers predominantly use level 2 charging at or near their homes (Fig. 18). Public charging use is likely influenced by free charging at some locations, which electric drivers tend to seek out and utilize through longer shifts.



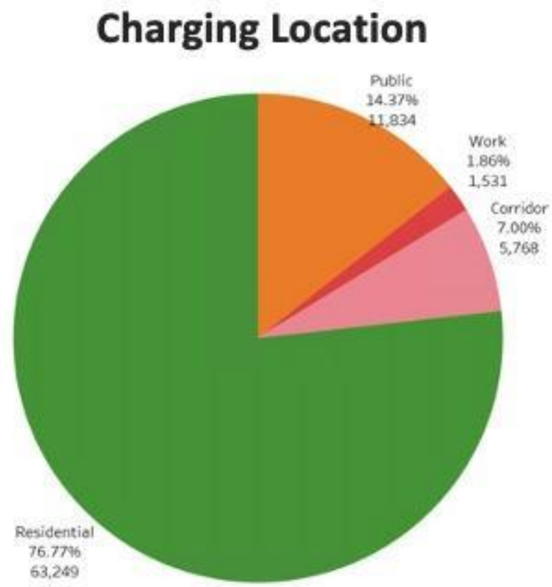


Figure 15. TNC EV drivers predominantly used L2 charger at or near their homes.

TNC Lessons Learned

The tracking and monitoring of electric TNC drivers in this project is useful as a case study for the future electrification efforts of rideshare platforms as well as some insight needed for broader transportation electrification in the Salt Lake City area. These high-mileage drivers are the best utilization case of testing the capacity of EVs. They drive constantly during a work shift locally, and are also traveling in their EVs on trips across multiple states for personal use. Often, a rider's first experience in an all-electric car is through the Lyft or Uber platform. This ongoing, large scale "ride and drive event" is a great opportunity to increase awareness of EVs.

The best benefit to the drivers reported were cost savings. Avoiding the pump and the maintenance shop is appealing to any driver, but especially for those who depend on a reliable car for their work. A rideshare driver's earnings are directly related to how much they have to spend on gas and maintenance; their take-home pay is what counts. All of the drivers we worked with in Salt Lake City are currently happy with cost savings on fuel and maintenance, and they are telling passengers about it. Keeping the cost of electricity and availability of charging stations accessible financially, for gig workers and otherwise, will help more drivers seriously consider this increasingly affordable option.

Tracking high-use vehicles has provided evidence that the applications for short-trip, local rideshare work is not the only use case rideshare drivers accomplish. The longer trips being taken convey that daily use can "go the distance" for almost any consumer. Electric vehicles are accomplishing cost savings for daily work needs and any personal needs, too. This moment in time is important to spread the word about the positive experiences of these high-mileage drivers.

Additional TNC Perspectives: Outreach to Drivers at Sundance Film Festival

A key annual driving event in Salt Lake City is the Sundance Film Festival. For rideshare drivers, it's an important earning opportunity as they fulfill transportation needs for event attendees. In 2020 Lyft provided a driver hub space near the Lyft pick up and drop off area: a place where drivers could take respite and use the restroom during these busy days. Forth coordinated with Lyft to set up a tabling event at this hub in an attempt to take the pulse of the driver market in the area--outside of the focus EV driving group.

One difficulty with this approach was that drivers were working long shifts and not necessarily interested in being approached in this environment. Despite this, Forth was still able to have interesting conversations about EVs with everyday SLC drivers, and eleven drivers completed a survey. Perceptions of EVs varied widely, especially compared to our typical EV-driving sample. Only three of the eleven respondents said they have driven an electric or hybrid vehicle.

Again, this was a small sample, but it did uncover some valuable insights from a more random group of drivers from the area. All but one person answered that they live in single-family residences. However, only one person replied that they have at-home charging availability. Then, when asked if their parking space is within 10 feet of a standard electrical outlet, seven replied "yes." This point demonstrates the need for education around at-home charging options and coincides with a lack of awareness of public charging in this sample; five of the eleven drivers (Fig. 19) did not know of charging stations in areas where they drive for work:

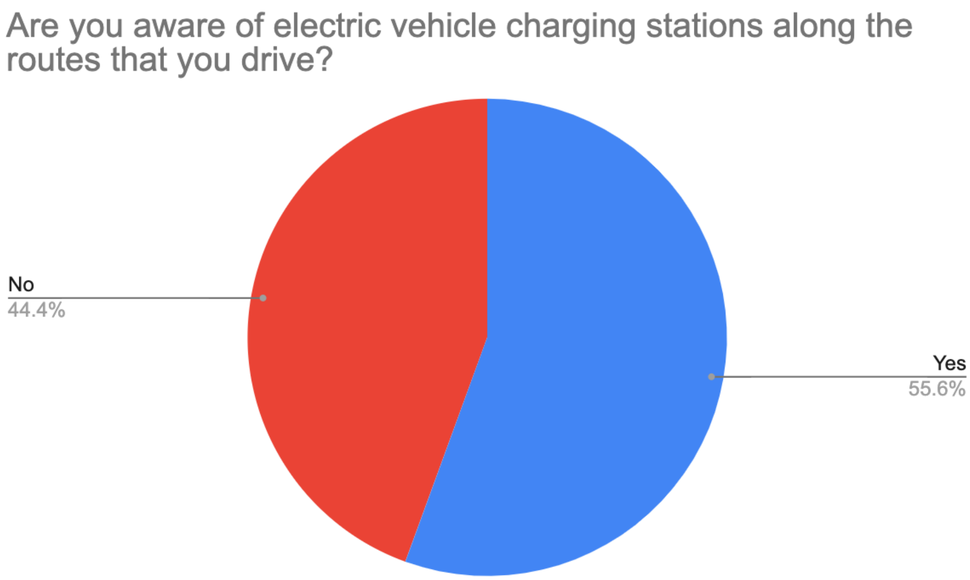


Figure 16. Sundance TNC drivers have a lack of awareness about chargers near their homes.

Three survey participants said that electric vehicles are "not as good" as gasoline vehicles. One person said they think they're "just as good." Two said they are "better than gas" cars, and one person said it "depends on the make and model." One reason a respondent provided as to why EVs were "not as good" is because there are "not enough places to charge." Another (who also noted that their personal driving includes lots of camping) stated "not enough off-road power."

The drivers were given an open-ended question about how many miles they estimate they drive in one month (Fig. 20). Answers ranged from 600-8,000 miles. Half of the drivers were between 600-2,000 miles. The other half of the drivers were a large step up in miles between 4,000-8,000 miles. This could indicate the difference between part-time and more full-time drivers.

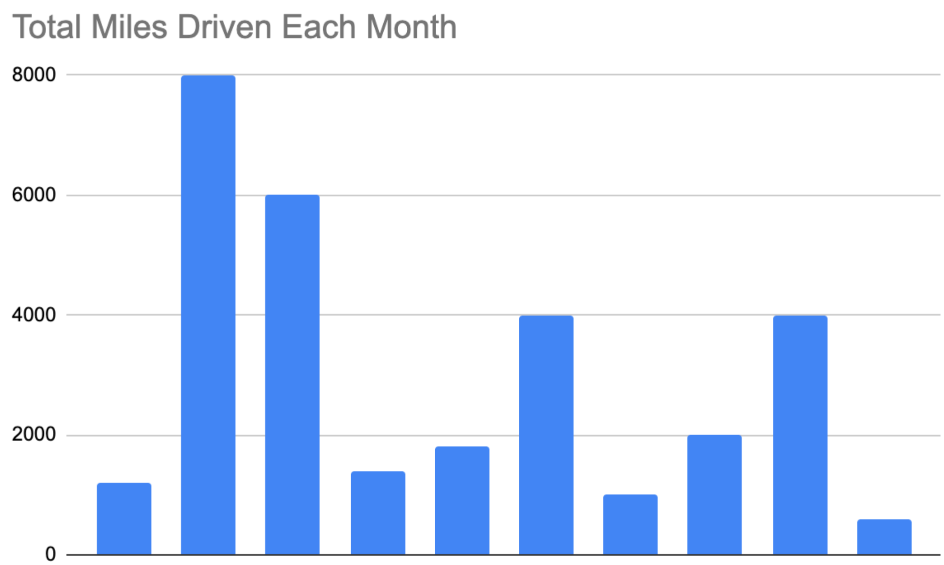


Figure 17. Sundance TNC drivers monthly driving estimates.

As mentioned, fuel costs are a constant expense for rideshare drivers and where electric vehicle drivers see a lot of savings add up. We asked the Sundance drivers how much they estimate spending on fuel in an average week with results shown in Figure 21.

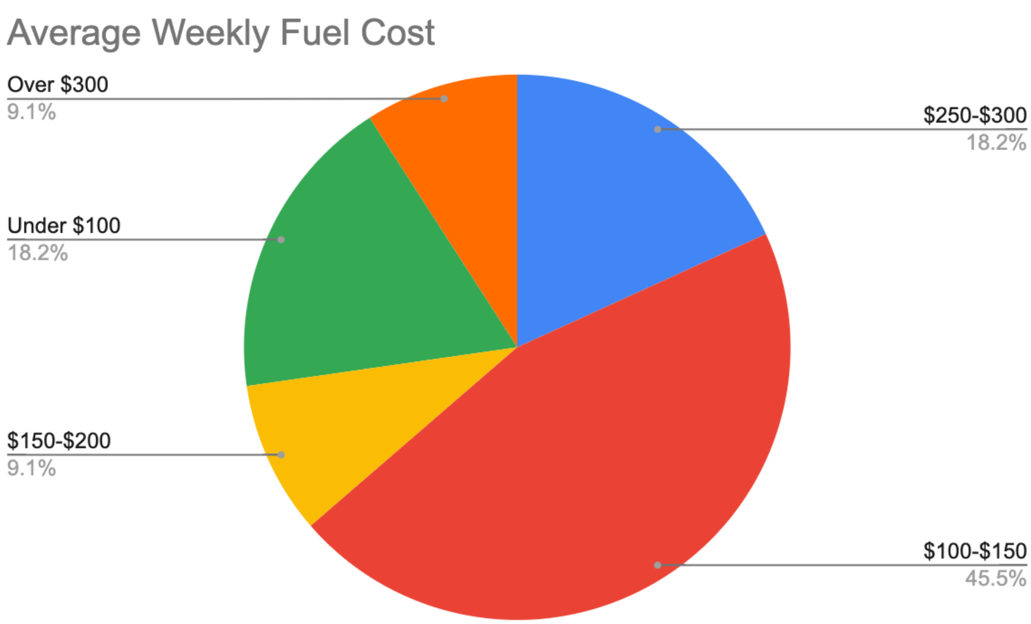


Figure 18. Sundance TNC drivers' average weekly fuel costs.

The next question was a bit more challenging for drivers to answer, and included some "don't know" or "it depends" answers. Drivers were asked how much they estimate spending on maintenance each year (Fig. 22) and the numerical responses were limited to eight participants. All but two gave amounts $1,300 and below. Two gave responses of each $3,000 and $3,500 respectively.

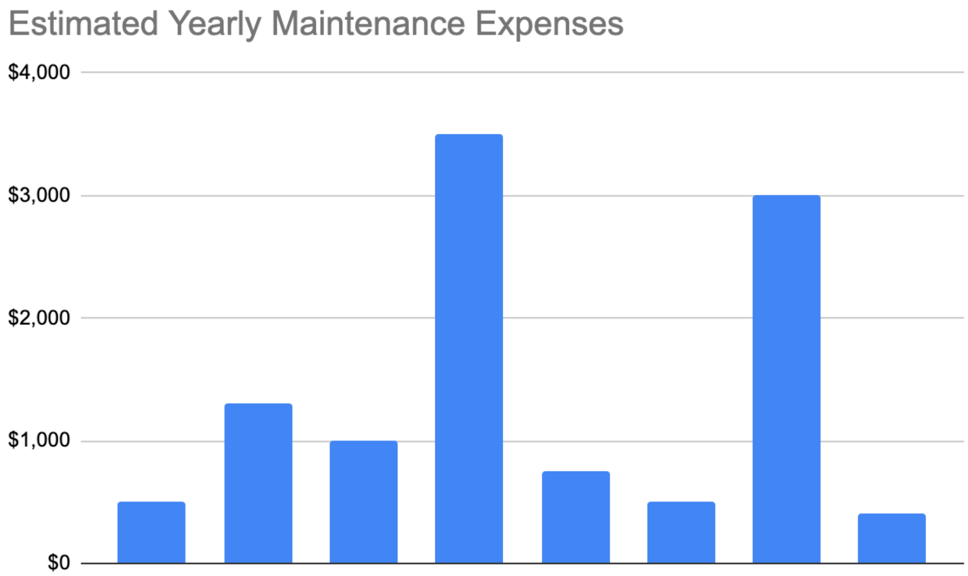


Figure 19. Sundance TNC drivers' maintenance expense estimates.
The year, make and model of the cars is important for drivers. Rideshare platforms require using a car less than 10 years old, and it must be in good working condition. An unexpected large maintenance expense can be a big setback for drivers not only because of the repair cost, but also because if their car has to be in the shop, they are missing days of work.

Maintenance adds up the most for the highest-mileage drivers. Not only is the wear and tear on their combustion-engine vehicle accumulating, but the frequency of oil changes increases with high use. Forth has learned from drivers that if they are full-time, they will have oil changes as often as once each month!

When it comes to transitioning to electric, range is a big issue. This is the case for everyday drivers, let alone those who drive all day for work. Nine total respondents (Fig. 23) gave feedback to our question: How many miles would a full battery electric vehicle need to travel on a single charge for you to be satisfied with the range?

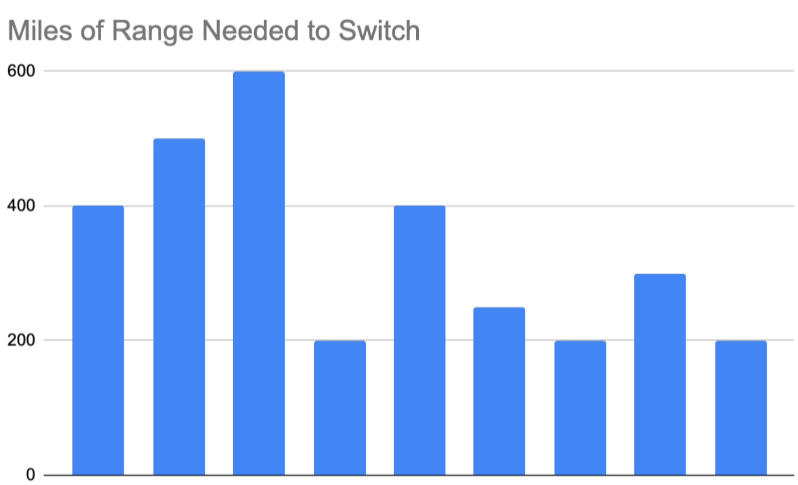


Figure 20. Sundance TNC drivers opinions about ranged needed to switch to EV.
We find it encouraging that half of the respondents gave answers of 300 miles and below, as this is already possible with some EV models.

Finally, we asked about the most compelling reason the driver would buy or lease an EV. Their top ranked answers are shown in Figure 24, with seven of the eleven reporting, fuel savings:

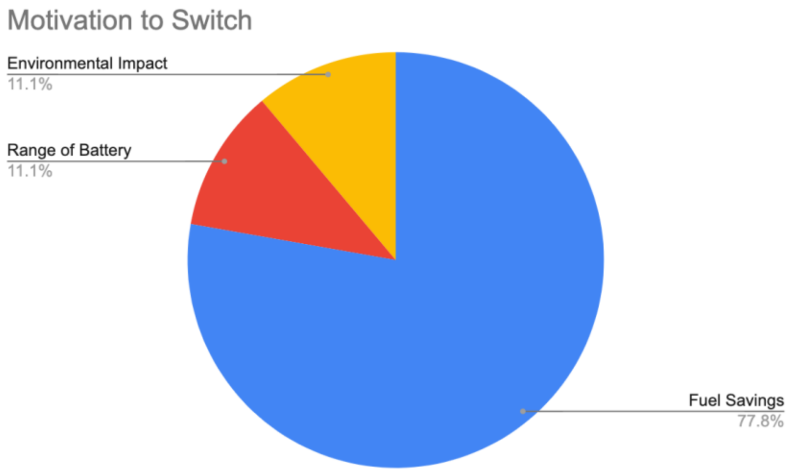


Figure 21. Sundance TNC drivers anticipated motivation to switch to EV.

Overall, the best value of this small sample is how random and unaffiliated each participant was. They were representative of a totally different set of drivers than the early adopter group Forth worked with that drive electric cars in Salt Lake City already. A couple of drivers let us know that they do *not* expect to consider an electric vehicle for their next purchase or lease, but one confirmed that they expect their next purchase to be electric.

3.4 Utility Integration

The proliferation of electric vehicle (EV) adoption introduces a suite of opportunities and risks to power system operation, which have the potential to significantly increase loading, reduce equipment lifespan, impact rate design and offer energy flexibility. The uncertainty in space, time, power and energy presented by EV charging demand creates a unique challenge to the development of utility best practices. This work in Y3 and through the project end sought to quantify EV charging uncertainty and its implications.

Charging Impacts on Distribution Systems

The DC Power Flow – Power Grid Impact Analysis (DCPF-PGIA) model first developed in (Palomino & Parvania, 2018) is extended to model transformer risk of failure in the presence of EV charging and rooftop solar generation. The DCPF-PGIA is a data-driven model that is flexibly configured so as to be broadly applicable to any distribution system for which data is available. The DCPF-PGIA relies on a Monte-Carlo simulation framework to realize probabilistic results that empower decision makers to make risk-based decisions in the face of an evolving EV load landscape.

Findings

The latest results in (Palomino & Parvania – Data-Driven, 2020) reinforce the findings of (Palomino & Parvania, 2018). Increased EV loading contributes to accelerated distribution transformer loss-of-life that is significantly, but not wholly compensated by the contribution of rooftop solar generation. This discrepancy is due to the asynchronism of peak rooftop solar generation and peak EV loading. The work in (Palomino & Parvania – Data-Driven, 2020) relates this overload risk to loss-of-life and risk as defined in (17):

$$p^{LoL} = (1 - \mathbf{X}(T/t)) \qquad (17)$$

where *T* represents the remaining lifespan of the transformer under study, *t* days until transformer service or replacement, and ***X*** the loss-of-life cumulative distribution function (CDF). This formulation enables operators to consider loss-of-life risks for legacy transformers given various maintenance plans. The loss-of-life CDFs for each study scenario are presented in Figure 25.

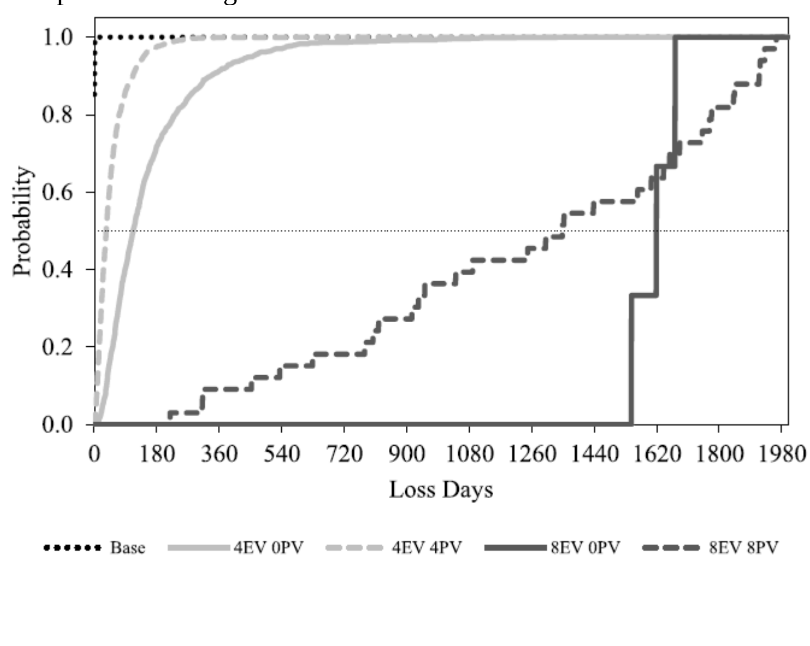


Figure 22. Transformer loss-of-life CDF risk across study scenarios.

For example, the maximum risk of failure for a 50kVA transformer with 3500 days of life remaining, in a 12-home study system with 4 EVs and 4 rooftop solar installations, falls from 81.83% to 48.25% when the days until service *t* is accelerated from 500 days to 100 days.

EV Charging Prediction
EV charging load poses overloading risks for distribution systems operation, while providing opportunities for distribution system operators (DSOs) to take advantage of EV charging flexibility for enhancing grid operation. Uncertainty limits the potential for beneficial EV charging flexibility control.

This work proposes a data-driven Bayesian hierarchical model (Fig. 26) to stochastically characterize the arrival of EVs to a fleet of charging stations. Bayesian hierarchical models offer two key advantages over deterministic approaches. First, a Bayesian approach represents all model parameters and predictions as probability distributions making it well suited for stochastic characterization. Second, hierarchical models enable the disaggregation of predictive distributions by explanatory variables, such as time, which better characterize time-bound stochastic processes.

Findings
The proposed model takes advantage of data collected from publicly sited EV charging stations in Salt Lake City to stochastically characterize EV charging load. Hourly EV arrival data is aggregated to form the model evidence. Then data-driven uniform hyper-priors are constructed to parameterize a gamma prior and Poisson likelihood, its conjugate function, in a stochastic and unbiased manner to yield predictive posterior counts for hourly EV arrivals.

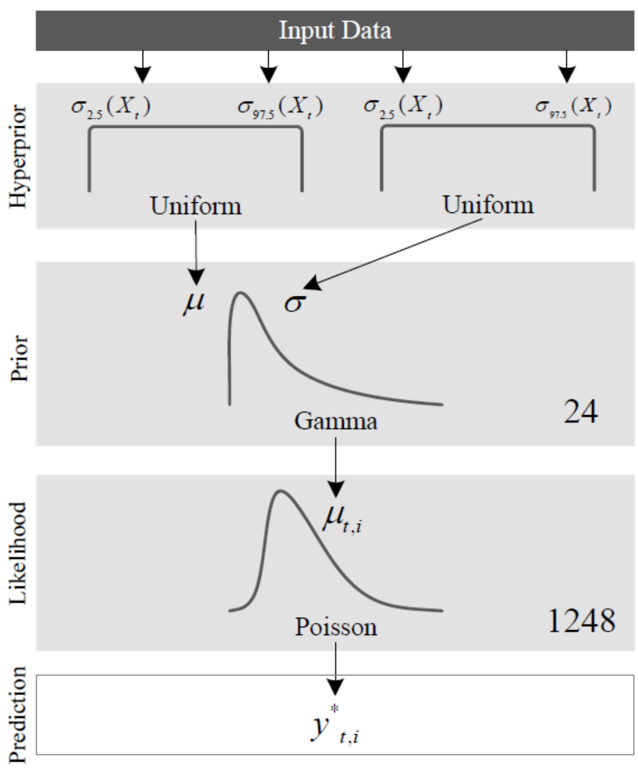


Figure 23. Bayesian hierarchical model.

The hierarchical model is implemented in python as a PyMC3 model. We take 2,000 MCMC tuning samples to burn in the model and then take an additional 8,000 samples to approximate the posterior distributions using the No-U Turn sampling algorithm in four sampling chains.

The rate of EV arrivals per hour presents a roughly bimodal distribution with peaks coincident with EV commuters arriving to work and returning from lunch as shown in Figure 27. Qualitatively, the hourly distributions resulting from the posterior predictions and testing data mirror each other closely.

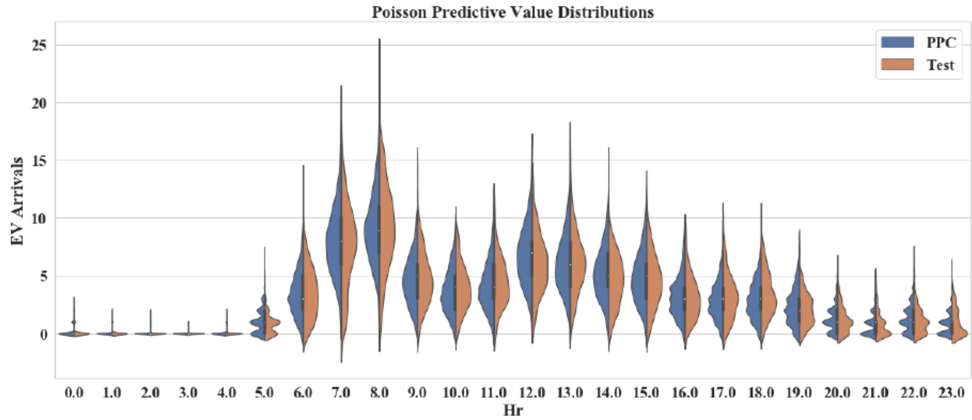


Figure 24. Predictive hourly distributions resulting from teh Poisson likelihood model and testing dataset.

The expectation of EV arrivals from the posterior distributions is overlapped with the expectation from the testing data in Figure 28. Comparison shows nearly identical EV arrival expectation and standard deviation, shown as shaded bounds, from both the Bayesian hierarchical model posterior predictive counts (PPC) and testing data.

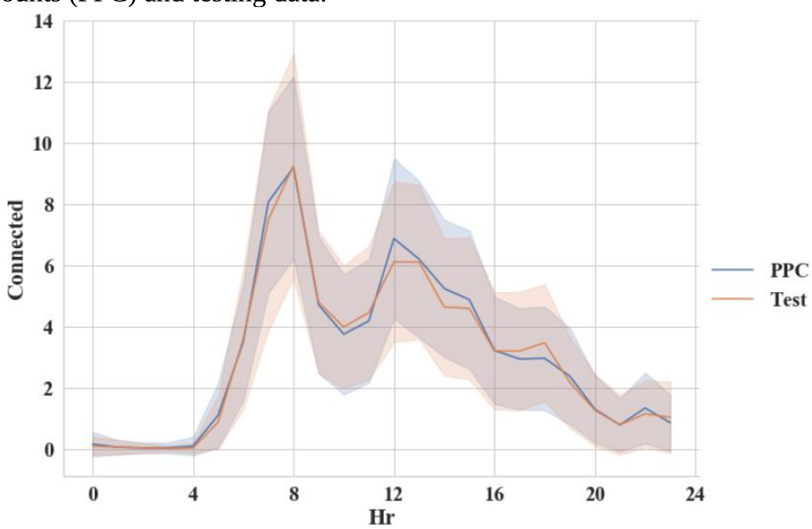


Figure 25. Hourly expectations distribution resulting from model prediction, PPC, and testing data.

Overall, model prediction in a SMAPE error of 2.38%. Across 5,016 evaluations, 209 test days with 24 hours each, nearly 80% of predictions are within 2 counts of the actual arrival observation. Further, greater than 50% of predictions are within 1 count of individual test day arrivals.

Residential charging impacts

Residential Load Model. A residential model was developed over the course of the program to approach transformer loading analysis. The model employs RMP typical layout and residential load data to construct a representative residential transformer load profile specific to the Salt Lake City area. Of particular interest was the impact of EV loading on top of the existing residential loading as EV penetration and charger capacity increase. The RMP layout provided shows two residential models for analysis: 50kVA transformer, 11 homes; 75kVA transformer, 15 homes. With these models in mind, we incorporated EV loading data to develop boundary conditions for each residential scenario. Boundary conditions such as maximum EV penetration, maximum EV charger capacity and maximum EV charge coincidence prior to equipment overload can be further studied to investigate mitigation strategies.

A key to this model was the INL EV Project, which aggregates data across 13 metropolitan study locations, greater than 6,000 participating electric vehicles and provides a broad foundation for WSEV research. INL EV Project Summary load and percent chargers connected data was employed to conduct a preliminary transformer loading impact study in collaboration with the RMP residential load data. Figure 29 presents these loading impact results with an INL "average EV" profile and three designed cases of differing charger capacities assuming a 25% EV penetration on the studied transformer.

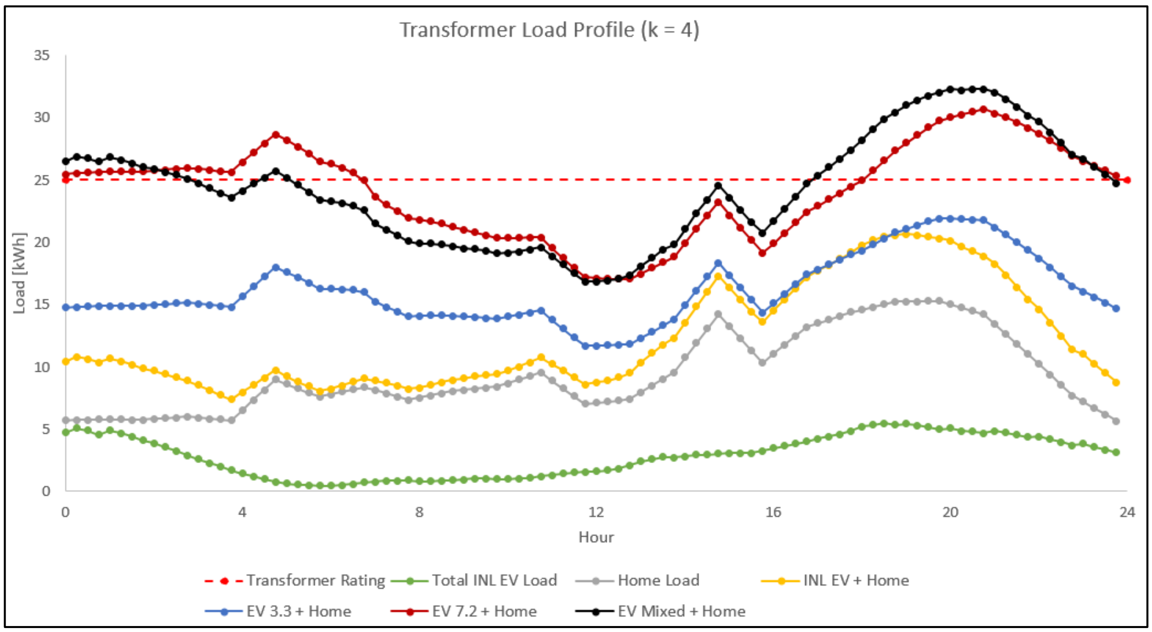


Figure 26. INL EV Project Summary data showing average load/EV per time sample on an "average day."

The INL "average EV" distills INL EV Project Summary data into an average load per EV per time sample on an "average day" which can then be used for a daily loading profile given some number of vehicles. Publicly available INL EV Project data provides foundational EV loading summary data.

The model developed offers a probabilistic simulation and analysis of transformer loading given randomly distributed home and electric vehicle loads. Probabilistic measures of risk are presented and recommendations are made for system planners to improve the sophistication of deterministic design guidelines to prepare for dynamic EV loading on legacy infrastructure.

Findings

Initiation of at-home electric vehicle charging sessions are relatively diverse. This finding indicates that the initiation of EV charging sessions are not likely to be coincident with one another. For reference, RMP guidelines specify a nearly linear estimate of coincidence factor for residential homes from 1.0 to 0.70 as the number of homes under consideration increases from 1 to 11. The EV coincidence factor curve is exponential and is approximately 0.30 with 2 EVs connected to a residential transformer. Current RMP guidelines do not consider an EV charging coincidence factor as independent from residential loading.

Electric vehicle charging presents highly uncertain loading. While loading does generally follow arrival behavior, loading can change in step-wise fashion from time period to time period as new EVs initiate charging sessions. Additionally, EV loading is highly varied. Minimum and maximum loading values observed can differ by as much 100kW under the 12.9kW – 6 EV study scenario. Transformer overload risk remains low at current and near term penetration levels and residential charging rates. Higher levels of penetration and high-power level 2 charging presents much greater risks levels, which may call for utility intervention.

For the Transformer Monitoring Sampling Rate, our experience informed us that EV load monitoring devices should sample power data at a rate of once per minute or faster. Consequently, our Grid 20/20 PDTM monitors were upgraded from 5-minute to 1-minute sampling intervals.

We also demonstrated that DC fast chargers are not all alike. For example, concerning DCFC reactive load in idle state, ChargePoint DC chargers presented a significant reactive power load. While we suspect that this behavior may be unique to ChargePoint models and is not representative of DC fast chargers generally, we shared this discovery with WSEV partners and recommended that detailed charger model analysis be completed prior to purchase and installation.

Implications for Best Practices

The team's utility integration researchers made the following recommendations to utility planners and distribution equipment operators.

- Planners should consider the development of system-wide permitting procedures for customers seeking approval for the installation of high capacity PEV chargers. Permitting these high capacity residential chargers serves to keep planners abreast of PEV growth on their system, both spatially and temporally, in order to better serve these new loads and appropriately plan for upgrades and maintenance.
- In the face of growing dynamism at the grid's edge, planners should consider the uncertain nature of loading with probabilistic methods, and planners must develop probabilistic perspectives and define what is an acceptable level of risk for status-quo operation and at what point is intervention needed to maintain reliability.
- Utilities might look at opportunities to leverage the emerging communication and control technologies for utilizing PEV charging load as a flexibility resources in distribution system operation.

3.4.1 Fast-charging station deployment for battery electric bus systems considering electricity demand charges.

Battery electric buses (BEBs) are considered a promising alternative for bus fleets to alleviate the growing environmental problems in urban areas, and fast-charging technology has been introduced to BEB systems to help electric buses provide uninterrupted service without the need to carry a large onboard battery. One general consensus is that high power demand of fast-charging stations may significantly increase the power cost (known as demand charges) associated with charging events, thus increasing the operational cost of BEBs and as a consequence, hindering BEB implementation. In the United States, the demand charge rate can be as high as $90/kW (McLaren et al., 2017). Qin et al. (2016) indicates that in Tallahassee, Florida, demand charges accounted for 75.2% $\pm$8.6% of the total electricity bill for a fleet of five electric buses. Therefore, the potential high demand charges should be considered when planning fast-charging stations for an electric bus system.

This work proposes an innovative model to select the optimal locations of fast-charging stations, determines the installation of energy storage systems for fast-charging stations, and designs the optimal battery capacity of electric buses for a fast-charging electric bus system. The model considers not only the trade-off between vehicle battery costs and charging station costs but also the trade-off between upfront costs and demand charges for an electric bus system. A numerical study based on an eight-line bus network in Salt Lake City (Fig. 30) is conducted to demonstrate the effectiveness of the proposed model.

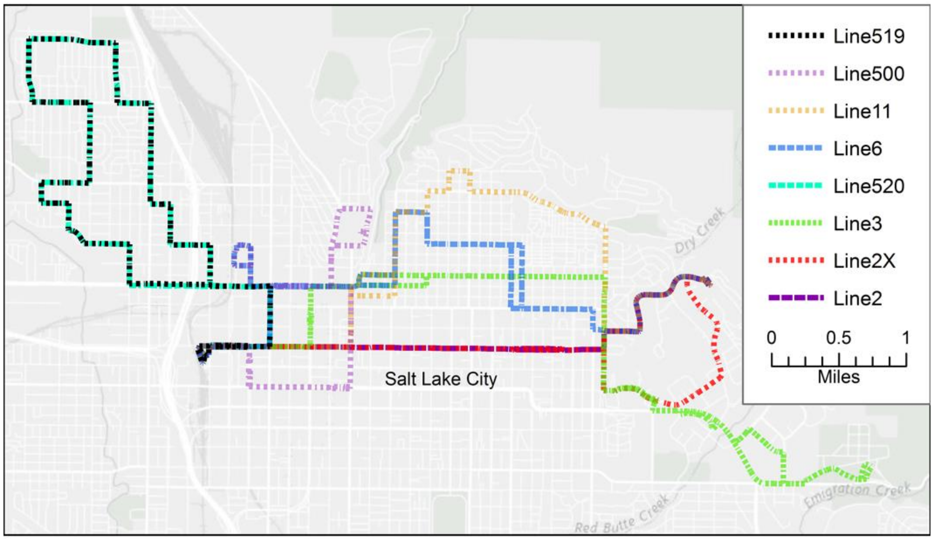


Figure 27. Eight-line bus network in Salt Lake City.

By implementing the proposed model on this eight-line network, we can obtain the optimal deployment of fast-charging stations and energy storage systems, as well as the optimal on-board battery capacity for each bus line. The optimal results are reported in Table 1. Figure 31 shows the deployment of fast-charging stations and energy storage systems. The fast-charging stations are located at either bus terminals, where buses can dwell for a relatively long time, or on-street bus stops that are shared by many bus lines. This result indicates that installing fast-charging stations at these locations can most effectively reduce the size and total cost of the bus system's on-board batteries. The total amortized cost of the bus system is $407,790, which consists of the battery cost of $158,100, the fast-charging station cost of $147,561, the ESS cost of $13,662, and the demand charge of $88,467. Note that the demand charge accounts for 21.7% of the total system cost and thus should not be neglected in practice.

Table 1. Optimal results.

Result	Value
Total amortized costs	$407,790
Amortized system battery costs	$158,100
Amortized fast-charging station costs	$147,561
Amortized energy storage costs	$13,662
Amortized demand charges	$88,467
Number of 150 kW fast-charging stations	8
Number of 300 kW fast-charging stations	9
Number of 10 kW energy storage chargers	17
Number of 20 kW energy storage chargers	1
Number of 50 kW energy storage chargers	7
Total capacity of all energy storage	196.5 kWh
Battery size of line 519	50.8 kWh
Battery size of line 520	51.1 kWh
Battery size of line 500	31.6 kWh
Battery size of line 11	28.6 kWh
Battery size of line 6	24.7 kWh
Battery size of line 3	46.0 kWh

Battery size of line 2	17.1 kWh
Battery size of line 2X	22.7 kWh

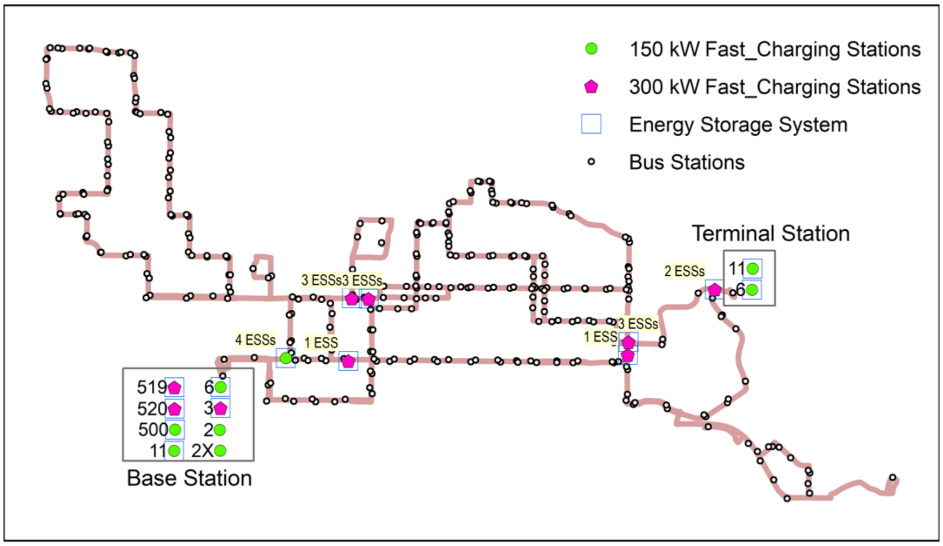


Figure 28. Deployment of fast charging stations and energy storage systems.

A fast-charging electric bus system can use small on-board batteries for BEBs but requires high cost of on-route fast-charging stations and energy storage systems, and high demand charges. On the other hand, an overnight depot-charging electric bus system uses cheaper depot chargers and off-peak charging but requires high battery cost. We further compare the total system cost of the eight-line bus network under the on-route fast-charging system and the depot-charging system. Based on the energy consumption simulation, we can calculate the minimum required battery size and depot charger power for each bus line, as shown in Table 2. For each bus line, the overnight depot-charging electric bus system requires much larger on-board batteries than the on-route fast-charging electric bus system. Table 3 compares the system cost of the on-route fast-charging system and the overnight depot-charging system. The total cost of the on-route fast-charging system is 50.7% less than that of the overnight depot charging system. Although the on-route fast-charging system requires higher cost for chargers, energy storage systems, and demand charges, it dramatically reduces the cost for on-board batteries. Therefore, for the tested bus network, the on-route fast-charging system is more economical than the overnight depot-charging system.

Table 2. On-board battery size and charger power for the overnight depot-charging electric bus system.

Bus line	Battery size	Charger power
519	559.5 kWh	50 kW
520	557.9 kWh	50 kW
500	267.7 kWh	20 kW
11	529.7 kWh	40 kW
6	323.9 kWh	20 kW
3	520.1 kWh	40 kW
2	437.3 kWh	30 kW
2X	488.4 kWh	30 kW

Table 3. Cost Comparison between the overnight depot charging system and the on-route fast charging system.

Cost Component	Overnight depot charging	On-route fast-charging
Battery costs	$816,912	$158,100
Charger costs	$10,602	$147,561
Energy storage costs	N/A	$13,662

Demand charges	N/A	$88,467
Total costs	$827,514	$407,790
Total cost savings	N/A	50.7%

Lessons Learned
This study proposes a mathematical model to optimize the planning of fast-charging stations for electric bus systems. The model simultaneously determines the deployment of fast-charging stations, the installation of ESSs, and the capacity of on-board batteries for BEBs. The proposed model includes the consideration of demand charges, a significant component of the bus operational cost that consistently has been ignored by previous literature. Numerical studies based on a real-world bus network were provided to demonstrate the effectiveness of the model. The results show that the proposed model can solve the *optimal planning problem of a fast-charging battery electric bus system*. The cost comparison between the overnight depot charging system and the on-route fast charging system indicates that considering current battery prices and charger prices, for the tested bus network, it is *more economical to deploy on-route fast charging stations*.

The proposed methodology offers a wide range of applications, the most suitable being within charging system design and on-board battery sizing for battery electric bus systems. The model not only considers the upfront cost for building a fast-charging electric bus system, but also considers the potentially high operational cost from demand charges. The model aims at determining the best trade-off among charger costs, on-board battery costs, energy storage costs, and demand charges. The model provides practitioners with an effective tool for planning fast-charging battery electric bus systems.

3.4.1.5 Optimal charging scheduling and management for fast-charging battery electric bus systems.

On-route fast-charging makes BEBs as capable as their diesel counterparts in terms of range and operating time. However, it is more challenging to schedule and manage charging events for a fast-charging BEB system. First, as has been discussed, on-route fast-charging may lead to high electricity power demand charges. Second, an increase in electricity energy charges may occur because of charging during on-peak hours. Without careful charging scheduling and management, on-route fast-charging may significantly increase fuel costs and reduce the economic attractiveness of BEBs. This next step in the work proposes a mathematical model to optimize the charging scheduling and management of a fast-charging BEB system, with the objective of minimizing total charging costs. Charging costs include both electricity demand charges and energy charges. The proposed model can handle bus systems with multiple bus lines and considers partial charging, demand charge, time-of-use (TOU) rate structure, and both charging scheduling and smart charging management. The proposed model is formulated as a linear program, which can be easily solved using off-the-shelf solvers, even for large-scale bus systems. The model is demonstrated with extensive numerical studies based on two bus networks in Salt Lake City.

A small network with six lines
A subnetwork of the bus system in downtown Salt Lake City, Utah, as shown in Figure 32, is considered in this scenario. The subnetwork includes one depot, three terminals, and six bus lines with a total number of 19 buses. We envision that the whole subnetwork will be served by fast-charging BEBs in the future. We assume that at each terminal of a bus line, an on-route fast charger will be installed for the bus line. All on-route fast chargers in the bus system are of the same type. The maximum charging power of an on-route fast charger is set to 325 kW. We further assume that each BEB will have a depot charger at its depot and all depot chargers in the bus system are of the same type. The maximum charging power of a depot charger is set to 130 kW. Although different bus lines may adopt different battery capacity, for the sake of analysis, we assume that all BEBs have an identical battery capacity of 330 kWh. The above charging power and battery capacity settings are consistent with the Proterra XR+ 40 foot BEBs (Proterra, 2018). The lower bound and upper bound of remaining battery power are respectively set to be 20% and 90%, respectively, of battery capacity. The proposed model in this study can help decision makers determine the optimal charging scheduling and management for the bus system. We consider an electricity rate structure with TOU plans that is shown in Table 4. The optimal charging schedules for the bus system are solved using the proposed model.

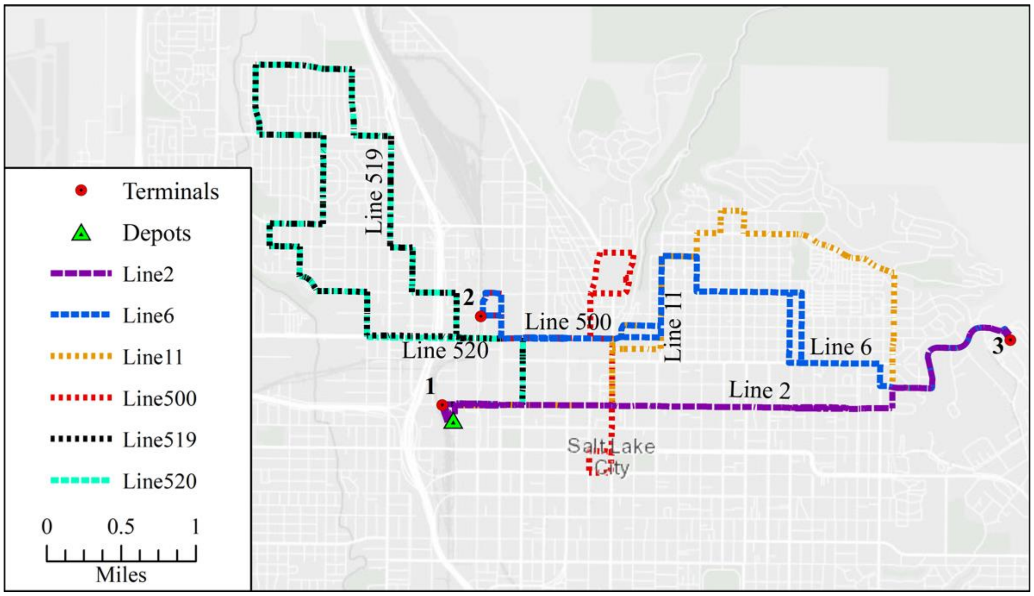


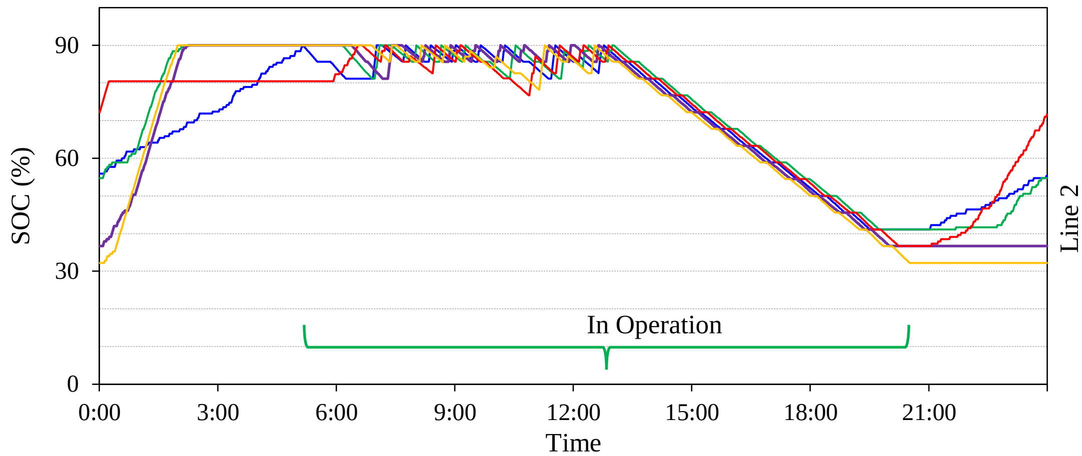
Figure 29. A six-line bus subnetwork in Salt Lake City.

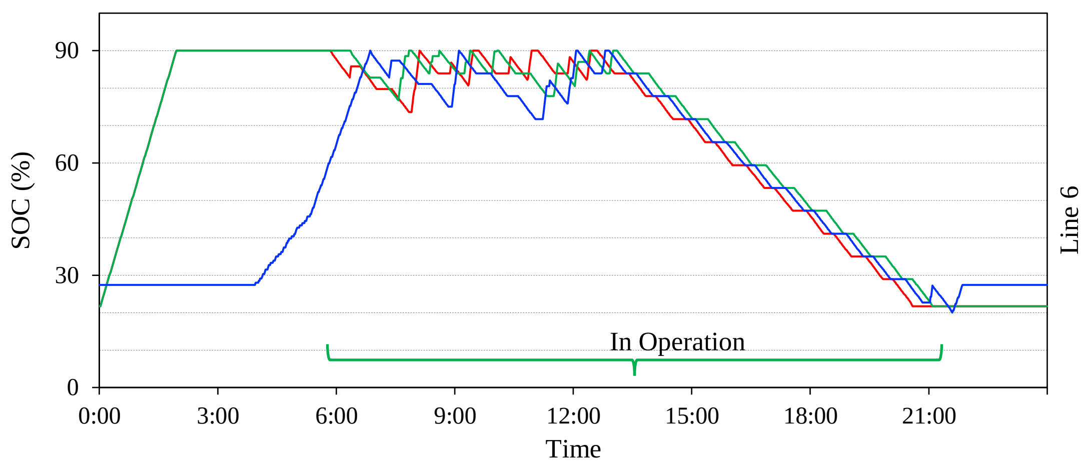
Table 4. Peak hours and price information.

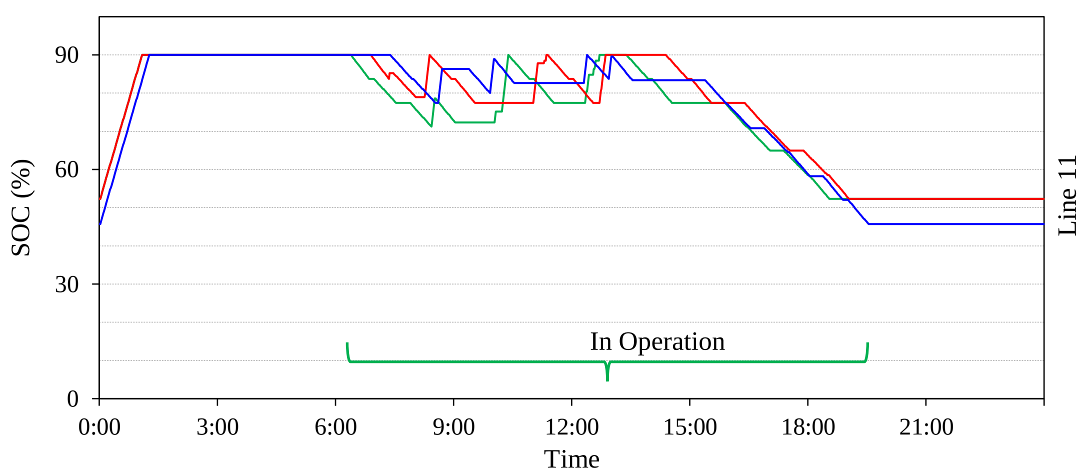
Month	May-September	October-April
On-peak hours	13:00 to 21:00	7:00 to 23:00
Off-peak hours	All other hours	All other hours
On-peak electricity rate	¢5.0209/kWh	¢3.9357/kWh
Off-peak electricity rate	¢3.3889/kWh	¢3.3889/kWh
On-peak demand charge rate	$15.40/kW	$11.08/kW
Off-peak demand charge rate	$0/kW	$0/kW

Figure 32 shows the battery state-of-charge (SOC) profiles of each BEB from the six bus lines under the optimal charging schedule from May to September. Note that the "In Operation" period shown in the figure is from the earliest service starting time to the latest service ending time. One can observe that the SOC of every BEB throughout a day is within the specified range (i.e., 20% to 90%), which implies that the optimal charging scheduling and management model can ensure the normal operation of the BEB system. One can also observe that none of the BEBs have rising SOC profiles between 13:00 to 21:00, meaning that no charging events are scheduled during peak hours. By scheduling all charging events during off-peak hours when both electricity rate and demand charge rate are much lower (compared to those during on-peak hours), the optimal charging scheduling and management model can minimize total charging costs of the bus system.

Figure 33 shows the battery SOC profiles of each BEB from the six bus lines from October to April. Several observations can be made from Figure 33. First, the SOC of every BEB throughout a day is within the specified range (i.e., 20% to 90%), meaning that the optimal charging schedule can ensure the normal operation of each BEB. Second, during operation, all BEBs utilize their batteries to the lower bound of the battery SOC (i.e., 20%) except one from bus line 520. By doing so, these BEBs can minimize charging during on-peak hours (i.e., 7:00 to 23:00). Note that the exceptional BEB from bus line 520 is not charged during operation, and its BEB is not utilized to the lower bound of the battery SOC only because its total energy consumption during operation is less than the total usable energy in the battery (i.e., $(90\% - 20\%)$ of the battery capacity). Third, for all BEBs, the overnight charging events at the depot are scheduled during off-peak hours. This result is expected because both the electricity rate and demand charge rate during off-peak hours are lower than those during on-peak hours.


SOC (%)
90
60
30
0
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
Time
In Operation
Line 2


SOC (%)
90
60
30
0
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
Time
In Operation
Line 6


SOC (%)
90
60
30
0
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
Time
In Operation
Line 11

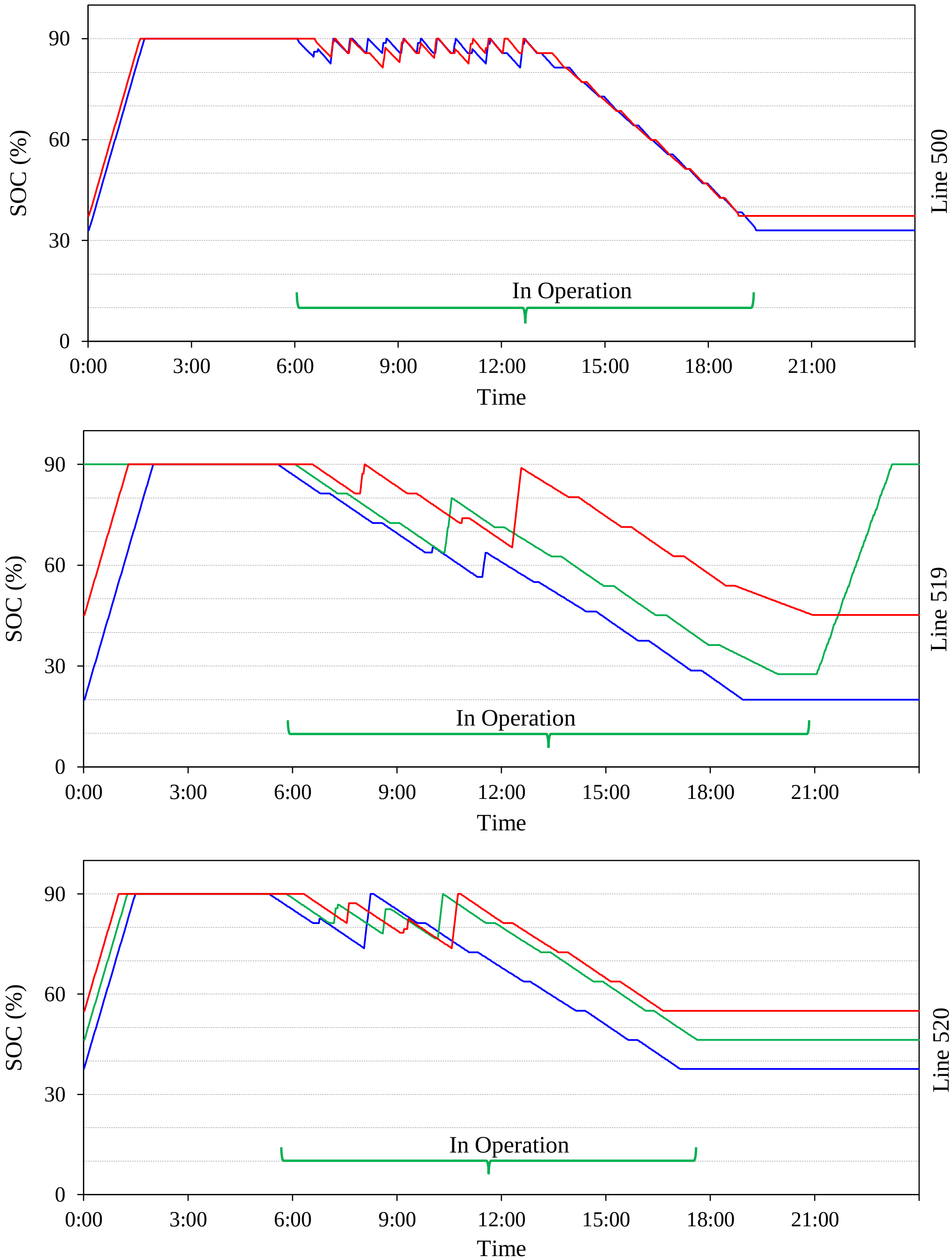
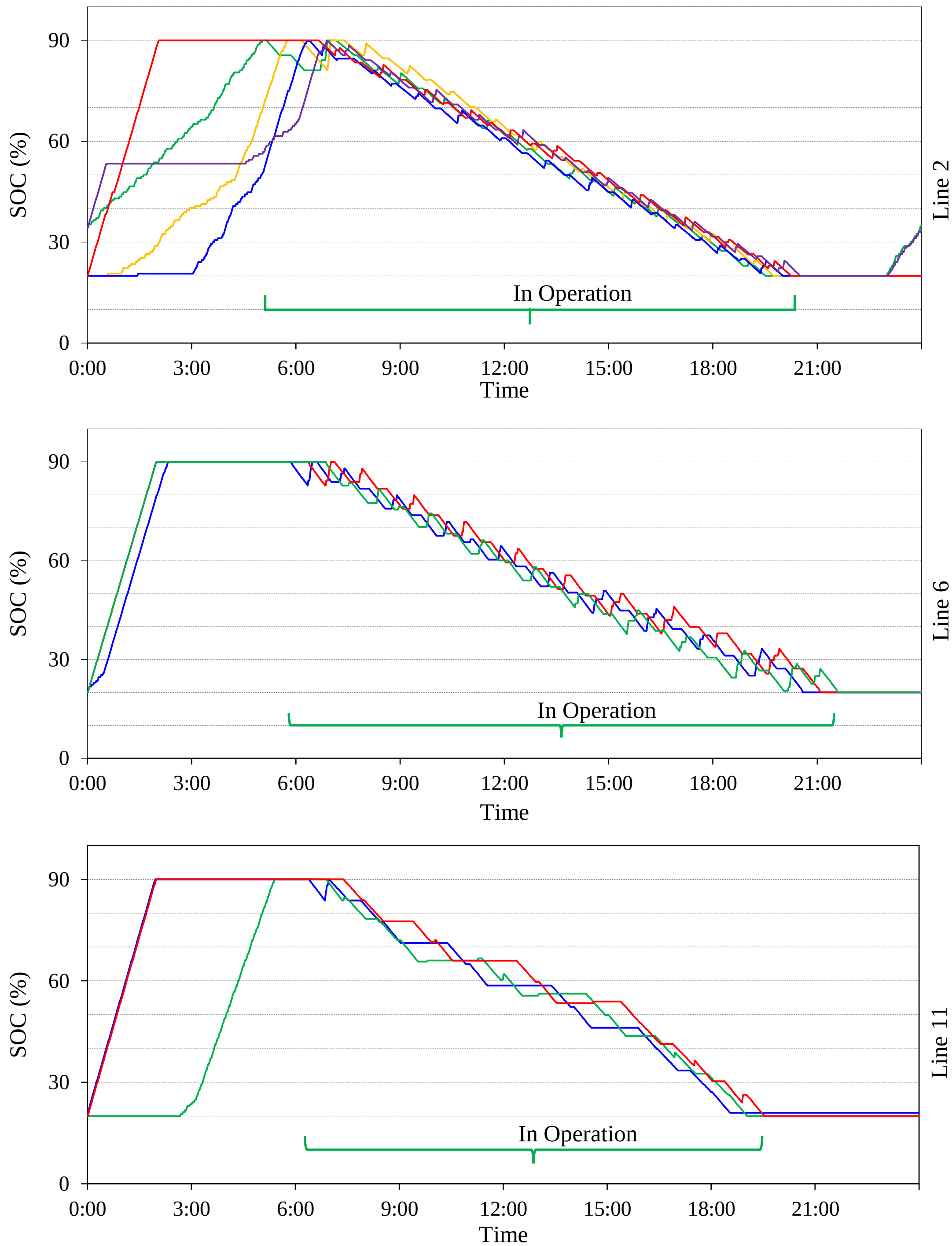


Figure 30. Battery SOC profiles for the six-line bus network during May to September.



90
60
30
0
SOC (%)
In Operation
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
Time
Line 2
90
60
30
0
SOC (%)
In Operation
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
Time
Line 6
90
60
30
0
SOC (%)
In Operation
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
Time
Line 11

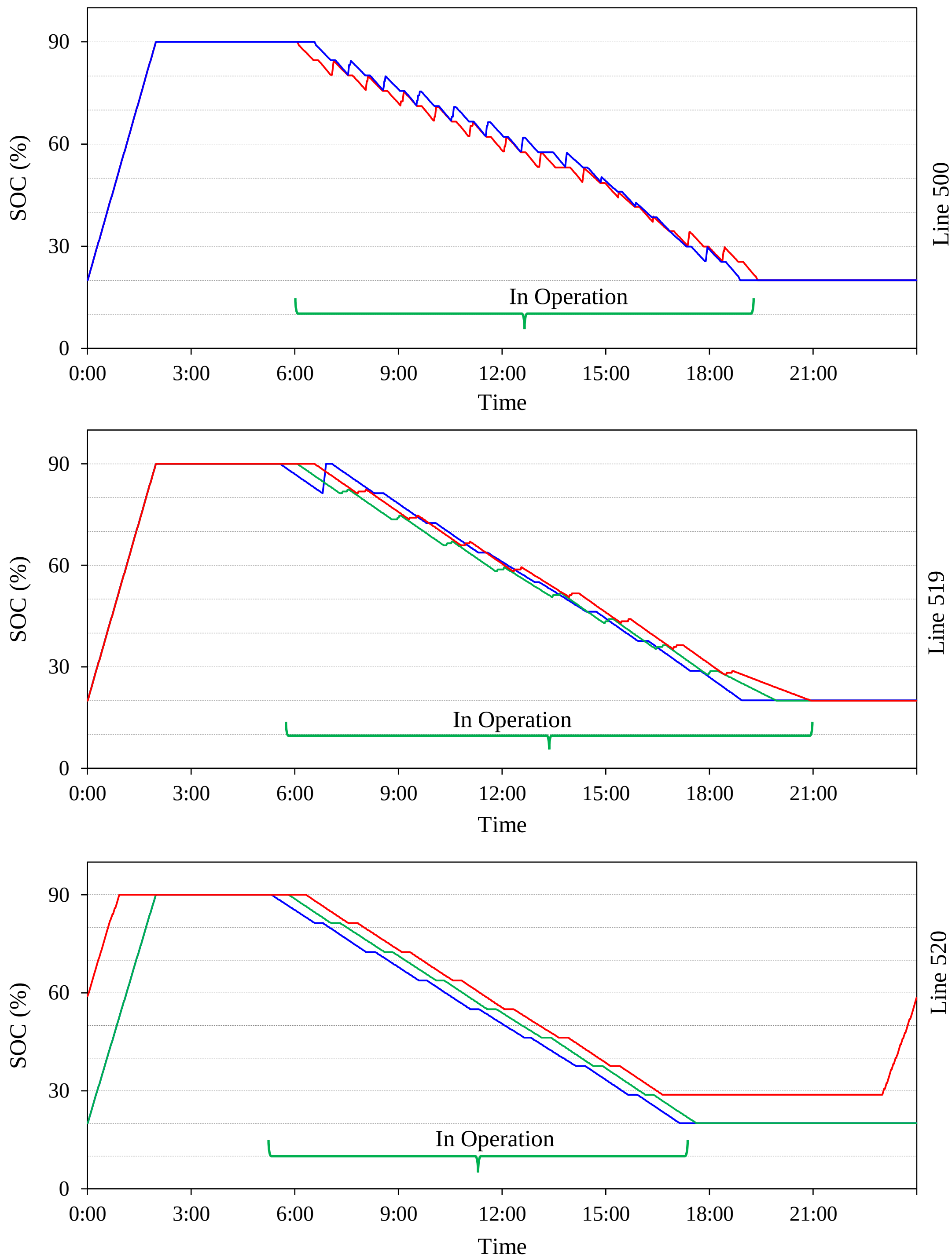


Figure 31. Battery SOC profiles for the six-line bus network during October to April.

In current practice, transit agencies usually charge a fast-charging BEB every time it stops at a fast-charging station (see, e.g., Eudy and Jeffers, 2017, 2018). This uncontrolled charging strategy may lead to high charging costs for a fast-charging BEB system. To demonstrate the benefits of the optimal charging scheduling and management, we further calculate the total charging costs of the six-line fast-charging BEB system under the uncontrolled charging strategy by simulation. The uncontrolled charging strategy assumes that each BEB is plugged in and charged as soon as it arrives at an on-route fast charger or a depot charger. Table 5 shows the cost comparison between the optimal and the uncontrolled charging strategy. Several observations can be made from Table 5. First, compared to the uncontrolled charging strategy, the optimal charging scheduling and management can significantly reduce total charging costs for both the period from May to September and the period from October to April. Second, the cost reduction mainly comes from the total demand charge reduction. This observation highlights the importance of considering demand charges in charging scheduling and management. Third, compared to the period from October to April, the period from May to September has lower total charging costs under optimal charging scheduling and management, although it has a higher electricity rate and demand charge rate during on-peak hours (see Table 4). Note that the peak hours for the period from May to September is 13:00 to 21:00, while the peak hours for the period from October to April is 7:00 to 23:00. For the period from May to September, all charging events are scheduled during off-peak hours. Consequently, both the demand charge and the energy charge are billed using the off-peak rates. For the period from October to April, however, the on-peak hours are so long that it is impossible to schedule all charging events during off-peak hours. On-peak charging leads to higher costs for both demand charge and energy charge.

Table 5. Cost comparison between the optimal charging strategy and the uncontrolled charging strategy.

Item		May-September			October-April		
		Uncontrolled	Optimal	Reduction	Uncontrolled	Optimal	Reduction
Total amortized daily charging costs		$878.6	$195.1	77.8%	$708.2	$239.4	66.2%
Total amortized daily demand charge		$635.1	$0.0	100.0%	$482.7	$37.6	92.2%
Total daily energy charge		$243.5	$195.1	19.9%	$225.5	$201.8	10.5%
Daily electricity consumption during on-peak hours		2,965.5 kWh	0 kWh	100.0%	5,561.7 kWh	1,234.8 kWh	77.8%
Total peak power demand during on-peak hours		1,237.2 kW	0 kW	100.0%	1,307.1 kW	101.7 kW	92.2%
Peak power demand during on-peak hours	Terminal 1	348.5 kW	0 kW	100.0%	355.8 kW	7.9 kW	97.8%
	Terminal 2	246.9 kW	0 kW	100.0%	262.4 kW	33.6 kW	87.2%
	Terminal 3	215.9 kW	0 kW	100.0%	263.0 kW	60.2 kW	77.1%
	Depot	425.9 kW	0 kW	100.0%	425.9 kW	0 kW	100.0%

A large network with 36 lines

To further test the proposed model on a large-scale bus network, we consider the bus system in Salt Lake County, Utah (see Figure 35), which includes two bus depots, 29 bus terminals, and 36 bus lines with a total number of 170 buses. We further envision that the bus network in Figure 34 is served by BEBs in the future. The bus line and timetable information can be obtained from Utah AGRC and UTA, respectively. The optimal charging scheduling and management for this large network are obtained by solving the proposed model. Table 6 reports the charging costs and computing time for this network. One can observe that the computing time is less than one minute, which illustrates the potential application of the proposed model in large-scale real-world bus networks.

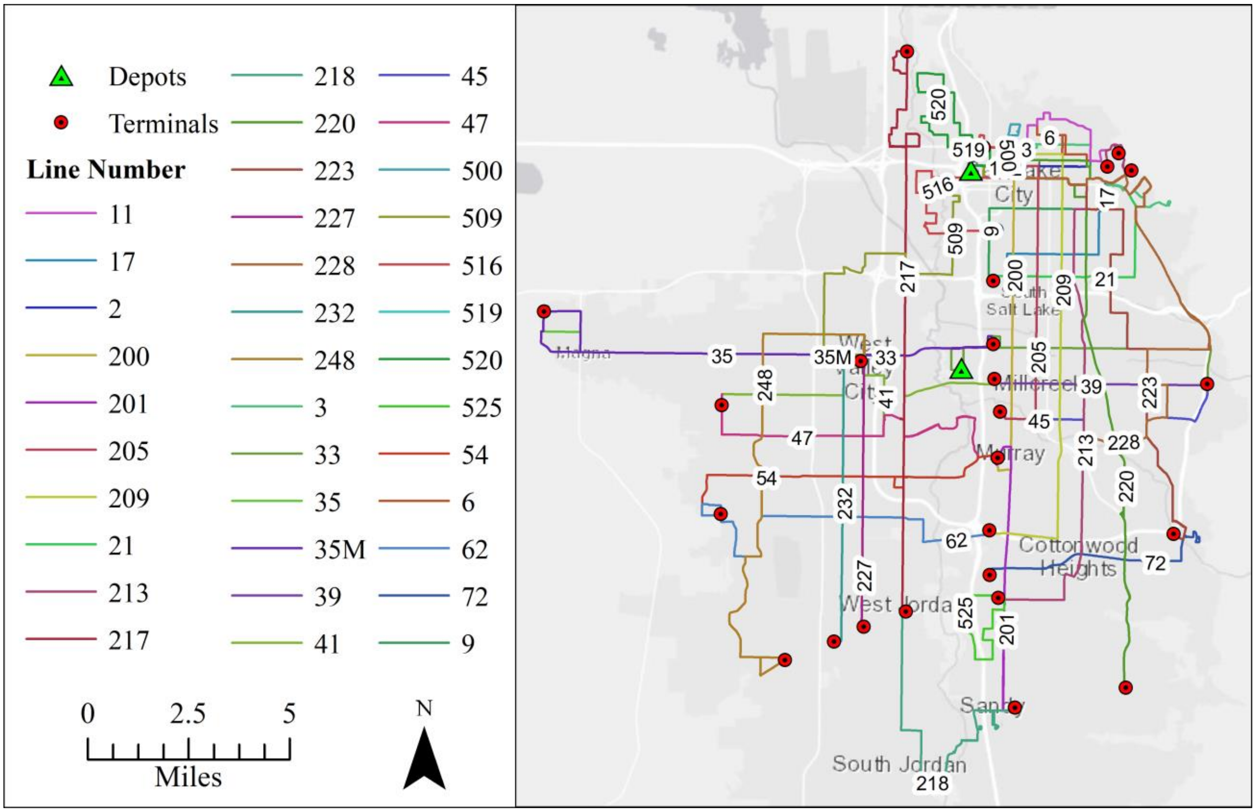


Figure 32. 36-line bus network in Salt Lake County.

Table 6. The results of the charging scheduling model for the Salt Lake County bus network.

Item	May-September	October-April
Total amortized daily charging costs	$3,120.3	$3,893.7
Total amortized daily demand charge	$430.6	$1,094.6
Total daily energy charge	$2,689.7	$2,799.1
Computing time (s)	35.2	37.5

Lessons learned

This study addresses the optimal charging scheduling problem for a fast-charging BEB system, considering electricity demand charges and TOU rate structure. The charging scheduling problem is formulated as a linear program, which is easy to solve, even for large-scale bus networks. The effectiveness of the model is demonstrated with extensive numerical studies based on two real-world bus systems, one with six bus lines and the other with 36 bus lines. The results reveal that the proposed model can effectively determine the optimal charging schedules for fast-charging BEB systems. The comparison between the optimal charging scheduling and management and the uncontrolled charging strategy demonstrates that *an optimized charging strategy can lead to significant savings in charging costs*.

The fast-charging battery electric bus system is rapidly being adopted by transit agencies around the world. The proposed modeling framework provides practitioners with an effective tool for the optimal charging scheduling of a fast-charging BEB system.

3.4.2 Implications for Best Practices

Preliminary results would indicate that "early adopter" TNC EV drivers tend to have at-home charging, and they also conduct their own research to facilitate their transition to electric. Considering varying access to at home charging, a key study finding indicates that readily available public charging is critical to transition. This is an overall implication across the WSEV project—that increased adoption, in particular in early years, will require expanded public charging regardless of EV usage contexts.

A key benefit to TNC EV drivers is cost savings. Since TNC EV drivers do not consider charging time as a challenge to their ability to make money, and considering that TNC EV drivers develop charging strategies to accommodate a minimum range for their driving needs, keeping the cost of electricity and availability of charging stations accessible financially, for gig workers and otherwise, will help more drivers seriously consider transition to EVs.

Considering utility integration lessons learned, gains can be made in the reliability of distribution systems if operators can develop risk-based failure tolerances and develop maintenance strategies accordingly. Additionally, Bayesian hierarchical modeling is well suited for the prediction of EV arrivals to publicly sited charging stations. *Utilities should collect data from available EV charging stations and develop Bayesian models for EV charging prediction* which can be updated as new data become available and charging behaviors evolve.

Switching from diesel buses to electric buses faces critical challenges, especially the financial barriers emerging from large capital expenses of vehicles and charging infrastructure and high operational costs from BEB charging. To overcome these barriers and promote effective adoption of electric buses, except for counting on technology advancement, it is also essential to develop cost-effective planning strategies from the strategic and operational perspectives. On-route fast charging station deployment and charging scheduling models can effectively reduce the upfront cost and the operational cost for BEB systems. Adopting these best practice will help *decide the optimal locations for charging facilities, types of BEBs to purchase, as well as BEB charging schedules*.

3.5 Public Outreach

3.5.1 Efforts and Lessons Learned Summary

In addition to ongoing communication efforts in particular by UCC and RMP, much of the outreach effort for WSEV has centered around the campaign "Live Electric" with highly shareable assets on the web, social media, and publicity and PR outlets while supporting and leveraging the resources and brand of project partners to increase awareness and participation across all identified targets of innovators and early adopters.

The general outreach goals and specific goals of Live Electric for year 3 and to end the project were to

- Socially, leave self-sustaining, task-relevant, social networks and promote user generated content
- Publicly, partner for events and support the presence and image of our "ambassadors" in traditional and new media outlets gaining them exposure and lasting success
- Leave lasting videos for education, documentary and archive purposes on the Live Electric website and YouTube channel as well as partner websites
- Update the Live Electric website with lasting, useful content to serve the community going forward

Social Media

Social media platforms have unique roles with regards to electrification and sustainability—the broader categories of EV adoption. On Twitter, daily, highly active, mostly political conversations on topics related to EV adoption play-out, but they are typically related in some manner to the news of the day. As Twitter itself has become a source of news, posts related to feeds that go viral can effectively piggyback on the story, but must, of course, keep in mind that the Live Electric partnership is bound by noncontroversial content and decorum. Facebook and Instagram have been used more for events, community organization and business sales and offers. YouTube has been active with random posts, but large subscriber bases are rare and require a regular posting schedule with ever increasing production value as audiences expect more even from DIY efforts doing reviews.

Complementing the Live Electric effort, the UCC social media outlets include Facebook, Instagram, Twitter, and LinkedIn. Through these four media outlets, UCC reaches over 2,500 subscribed readers with each weekly post. Since implementing social media platforms, UCC has seen an increased awareness of alternative fuels, industry news, UCC events, webinars, and UCC member and project highlights. Additionally, UCC social media platforms have increased Live Electric website traffic, by sharing EV content related to the work in this project.

Publicity

Publicity must find relevance and contribute to existing topical news to garner interest enough to get the local news stations to come out and cover an event, e.g., clean air event on red air days while promoting EVs as the solution. Additionally, hosting events with community and business partners with mutually beneficial interests for announcements or special offers draws the public, which in turns draws the media. As part of the publicity effort, UCC delivers a monthly newsletter to over 3,000 stakeholders with a high email-open rate of an average of 30%. This outreach includes events, workshops, and information to support AFV fleets and offers resources for technical support, grants, and incentives on both state and national levels. Work Electric workshops are promoted in UCC's monthly newsletter, and follow-up reviews to further support real and potential interest are highlighted. The newsletters are the first level of promotion for Work Electric and its participating partners.

Videos

Outreach videos are effective "attention getting" tools—highly shareable, easy to consume—but lose relevance rapidly depending on the style of the video. The more relevant to the times—newsworthy or fashionable with higher production value—with regards to style and content, the more effective the video, but the more quickly the videos become dated. However, the basic key messaging for WSEV has not changed significantly, e.g., the numbers concerning range anxiety may have changed, but range anxiety is still a key barrier to entry. Videos should be updated with current stylistic trends, fresh creative, current products, e.g., cars appearing in the videos, and other stylistic cues that date the video. Making timeless, or 'evergreen" videos, proves difficult though "recent" historical documentary videos (histories focusing on recent news) prove to have a longer shelf-life.

Website

The Live Electric website received a lot of unique visits instead of reoccurring visitors. In this way it exists as an anchor for the public. Leveraging the support and effectively the endorsement of all of the WSEV community partners under the campaign, Live Electric proves to be a valuable source of public trust, which is consistent with the 2017/18 focus group findings, i.e., the general public trusts a partnership made up of the public utility, local nonprofits, local universities, local businesses and the DOE far more than they trust any single institution or source on its own. Again, complementing the Live Electric efforts are all the partners' websites with their WSEV associated content. For example, the UCC website is a "transportation portal for advanced fuels" for Utah's large base of stakeholders and members. The site is dedicated to all UCC's activities and projects and includes noteworthy blog topics related to EVs, partnership and member recognition and the Green Fleets program. UCC has a dedicated page and links for Live Electric and Work Electric with all the resources to guide and direct to the resources in addition to contacts to bring potential partners on board as an actual participant of the Work Electric and Live Electric incentive program.

3.5.2 Implications for Best Practices

The Social Media channels @LiveElectricNow on YouTube, Twitter, and Instagram should mirror coinciding efforts to substantially contribute to the discussion and impart useful, prosocial information. Trolls can be redirected in a positive way, which proves more effective over disruptive efforts. Our audiences are looking for reliable sources, not posts that dip in and out randomly and get involved in outside issues.

Relative to Publicity generally, publicity and events prove to be most effective when joining forces with businesses or other partners with shared interests. The events become newsworthy in and of themselves. Involving state and local government officials (state senators, mayors, etc.) has consistently brought out the local news. Community and business partners with mutually beneficial interests are necessary to generate traditional media interest. Videos should be updated with current stylistic trends and fresh, creative and current products. The website, www.liveelectric.org, can exist in virtual perpetuity by disseminating useful agreed-upon information making only minor quarterly and calendar updates to the content.

3.6 EV Adoption Model

3.6.1 Efforts and Lessons Learned Summary

Electric Vehicle (EV) adoption is highly dependent on certain variables, including gasoline price fluctuations, financial incentives, infrastructure availability, and user socio-economic factors. Therefore, it is important to explore the weights of these variables to implement effective policies to promote EV adoption. By calibrating the panel data regression model using the collected historical data from 2011 to 2016 for 49 states, we find that the coefficient for the number of fast chargers is statistically significant and is 34.49 (as presented in the WSEV Y2 report). Based on this data, the fast charger installation data was collected from Rocky Mountain Power, and the up to date EV adoption data were collected from the Alliance of Automobile Manufacturers (AAM) and Utah Division of Motor Vehicles (Utah DMV), we can estimate the EV adoption data (from 2017 to 2020) under the hypothetical scenario that the support for the WSEV project does not exists. Then, based on the actual EV adoption data and the estimated EV adoption data under the scenario without the project, the Bass model can predict the long-term impact of the project on EV adoption in Utah, as shown in Figure 36. One can observe that the WSEV project has significantly accelerated the diffusion of EVs in Utah.

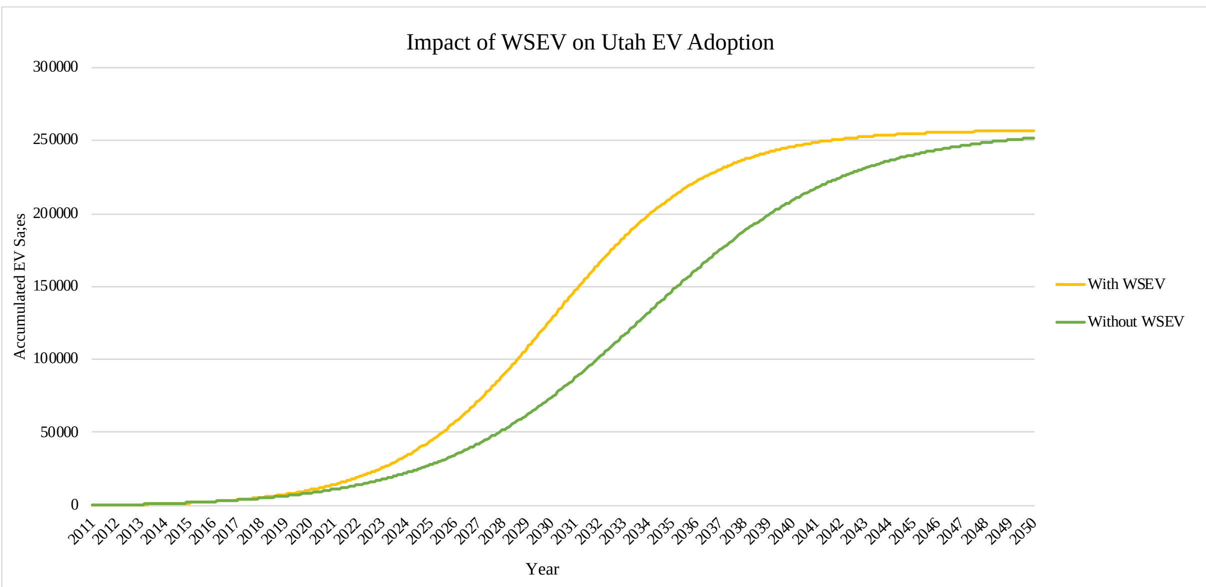


Figure 33. Utah EV Adoption Forecasting under Different Scenarios.

3.6.2 Implications for Best Practices

Based on the up to date EV sales data in Utah, the Bass model is recalibrated and it forecasts that with the support from the WSEV program, the total EV sales by 2026 will reach 56,870, which exceeds the impact goals proposed at the project's outset (i.e., the overall target impact of the program is to double the growth rate of PEVs in the region from 20% to 40% leading to more than 50,000 PEVs within 10 years). In addition, using the panel regression model combined with the Bass model, the EV adoption under the hypothetical scenario without the WSEV program can be analyzed. Without WSEV, the predicted total EV sales by 2026 would only be 34,475. The results demonstrate that, due to the deployment of chargers and other WSEV activities, the EV adoption in Utah has been and will continue to be significantly accelerated.

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