Measuring the Benefits of Public Chargers and Improving Infrastructure Deployments Using Advanced Simulation Tools

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Abstract

With support from the U.S. Department of Energy's Vehicle Technologies Office, the National Renewable Energy Laboratory developed BLAST-V—the Battery Lifetime Analysis and Simulation Tool for Vehicles. The addition of high-resolution spatial-temporal travel histories enables BLAST-V to investigate user-defined infrastructure rollouts of publically accessible charging infrastructure, as well as quantify impacts on vehicle and station owners in terms of improved vehicle utility and station throughput. This paper presents simulation outputs from BLAST-V that quantify the utility improvements of multiple distinct rollouts of publically available Level 2 electric vehicle supply equipment (EVSE) in the Seattle, Washington, metropolitan area. Publically available data on existing Level 2 EVSE are also used as an input to BLAST-V. The resulting vehicle utility is compared to a number of mock rollout scenarios. Discussion focuses on the estimated number of Level 2 stations necessary to substantially increase vehicle utility and how stations can be strategically sited to maximize their potential benefit to prospective electric vehicle owners.

Introduction

Battery electric vehicles (BEVs) are seen as an advanced vehicle technology with the potential to reduce petroleum consumption, decrease greenhouse gases, and improve air quality (the latter two depending upon the generation mix of the electric power grid). The market potential of BEVs is likely constrained by current battery technology, which limits single-charge driving range and requires relatively long recharge times. Advocates argue that increased access to public charging stations or electric vehicle supply equipment (EVSE) would spur increased rates of consumer adoption by increasing vehicle range between charges at the vehicle's home location and by psychologically minimizing the effect of range anxiety.

Unfortunately, the relationship between BEV utility and access to public EVSE is difficult to quantify (utility is used in this paper to express the percent of travel accomplished with a BEV relative to a conventional vehicle or CV). Recent efforts by Idaho National Laboratory as part of the EV Project [1] have provided real-world public charging data from early BEV adopters (primarily of Nissan Leafs). While reporting that approximately 15% of sampled charging occurs away from the vehicle's home location [2], it is impossible to calculate how much additional utility the owner would have achieved if his/her BEV had range and recharge/refill characteristics similar to a standard gasoline vehicle (e.g., how many times was the BEV forgone in favor of an alternate form of transportation on account of range limitation?).

Quantification of BEV utility relative to travel accommodated by a CV is a problem that lends itself nicely to a modeling and simulation approach. Researchers at the University of California, Davis have taken such an approach by linking spatial travel data with a simplified vehicle model in a geographic information system environment [3]. This geographic information system tool has been used primarily to evaluate and optimally locate public EVSE in California. Lawrence Berkeley National Laboratory has taken a similar approach in developing the V2G-Sim tool that, in addition to spatial travel data, leverages detailed powertrain simulation and battery life modeling to estimate impacts of various vehicle-to-grid communication and power flow scenarios [4]. Oak Ridge National Laboratory also has ongoing modeling and simulation activities related to assessing impacts of charging availability on electric vehicle utility and energy outcomes [5].

With support from the U.S. Department of Energy's Vehicle Technologies Office, the National Renewable Energy Laboratory developed BLAST-V—the Battery Lifetime Analysis and Simulation Tool for Vehicles. BLAST-V has been previously used in parallel with travel data from the Seattle, Washington, metropolitan area to quantify vehicle utility and battery life outcomes resulting from various levels of charging availability [6]. However, that analysis featured limited spatial resolution and thus evaluated public charging at various power levels assuming ubiquitous availability (essentially placing EVSE at every trip destination in the dataset).

This paper discusses updated spatial capabilities within BLAST-V for evaluating utilization of and incremental utility afforded by various public EVSE scenarios. The analysis focuses on quantifying impacts of multiple distinct rollouts of publically available Level 2 EVSE in the Seattle metropolitan area. Publically available data on existing Level 2 EVSE are also used as an input to BLAST-V with resulting vehicle utility compared to a number of mock rollout scenarios. The discussion focuses on the estimated number of Level 2 stations necessary to substantially increase vehicle utility and how stations can be strategically sited to maximize their potential benefit to prospective electric vehicle owners.

BLAST-V for BEV Utility Estimation

Nominal Capabilities

BLAST-V is an electric vehicle simulator that focuses on computing long-term effects of complex operational scenarios on vehicle utility and battery performance. It considers the vehicle powertrain, battery control strategy, driving and charging patterns, local climate, the vehicle-battery-environment thermal system, battery chemistry, and other factors in computing short-term vehicle and battery performance (e.g., vehicle range, battery voltage, state of charge (SOC), and temperature) and long-term vehicle utility and battery degradation. An approximate graphical representation of the key elements and flow of data within BLAST-V is illustrated in Figure 1. Further detail on the methods employed in this simulation can be found in [7].

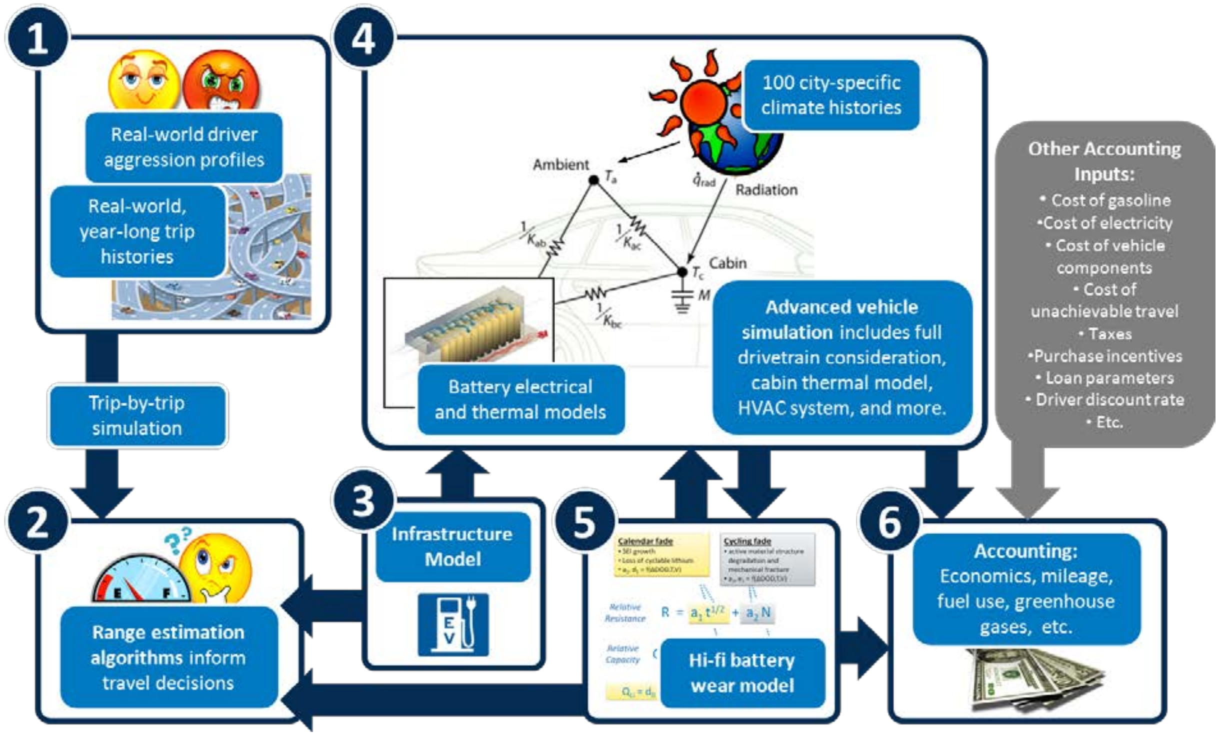

Figure 1. Graphical illustration of BLAST-V simulation algorithms.

A determination of which trips to take with a BEV and which to forgo is a key element of BLAST-V. As the driving patterns input are generally sourced from real-world operation of CVs, certain trips (and sequences of trips) will exceed the driving range of the simulated BEV and result in full battery depletion. Given the cost and inconvenience associated with stranded vehicles, BLAST-V assumes BEV drivers will rely on conservative estimates of vehicle range and a detailed knowledge of travel itineraries to avoid running out of charge mid-trip.

BLAST-V structures travel data as a sequence of tours. Each tour consists of consecutive trips with the first trip beginning and the last trip ending at the vehicle's home location (with assumed access to charging). Prior to the start of each tour, BLAST-V considers the battery's current SOC, distance and expected duration of pending trips in the tour, historical depletion rates from similar trips, and the availability of work/public EVSE to estimate battery SOC throughout the potential tour. This estimated SOC informs a go/no-go decision at the beginning of each tour. If the estimated SOC is maintained above a specified threshold for the entire tour, the simulated driver selects the BEV for travel and the tour is simulated in greater detail, considering electrical, thermal, and life models of the battery pack. However, if battery SOC is estimated to be depleted below the specified threshold, the driver forgoes use of the BEV and electrical, thermal, and life models of the battery pack are simulated with the vehicle in its parked mode for the duration of the tour. While BLAST-V is not primarily concerned with alternate travel modes in situations where BEV travel is forgone, it is reasonable to assume that real-world drivers would coordinate use of a secondary household vehicle (likely a CV), arrange for a short-term rental vehicle, utilize some form of public transportation, plan a carpool, or potentially omit the tour entirely.

BLAST-V's go/no-go decision for determining BEV travel is believed to mirror the way that real-world drivers make personal travel decisions. By implementing a low-order planning model prior to tour evaluation, BLAST-V simulates the hundreds of tour decisions a driver makes every year when determining whether his/her BEV is suitable for a particular tour.

Spatial Enhancements

Recent upgrades to BLAST-V include the addition of detailed spatial travel data and charging logic that enables vehicles to charge away from home when in the presence of public EVSE. In addition to travel information, including trip start/end time, distance, and destination code (home, work, public), BLAST-V now accepts latitude/longitude coordinates defining trip destination locations. These spatially resolved destination locations are used by BLAST-V in parallel with user-defined public EVSE rollouts, where each charging station is defined by a latitude/longitude position and maximum charging power. During the tour planning and evaluation phases, BLAST-V calculates the distance between the vehicle's current parked location and the nearest public charging station. If the distance is within a predefined threshold, the vehicle is simulated as plugged in to the charging station and accepting electricity as necessary.

Analysis

Simulation Parameters

Having established a methodology for estimating BEV utility that is sensitive to user-defined rollouts of public EVSE, the next step is to investigate various deployments of public charging infrastructure. In doing so, a number of simulation parameters must be defined, including travel profiles, driver behavior, vehicle performance, battery attributes, environmental conditions, and charging infrastructure.

Travel Profiles

Herein we employ historical travel data from the Puget Sound Regional Council's (PSRC's) Traffic Choices Study [8], processed per [7] to yield 317 real-world travel histories, each consisting of 365 continuous days of uninterrupted data. The resulting histories provide trip distance, trip and park durations, and destination data for each trip event. The data include codes such as home, work, or public in addition to precise latitude/longitude coordinates. Relevant statistics for the 317 vehicle samples are shown in Figure 2.

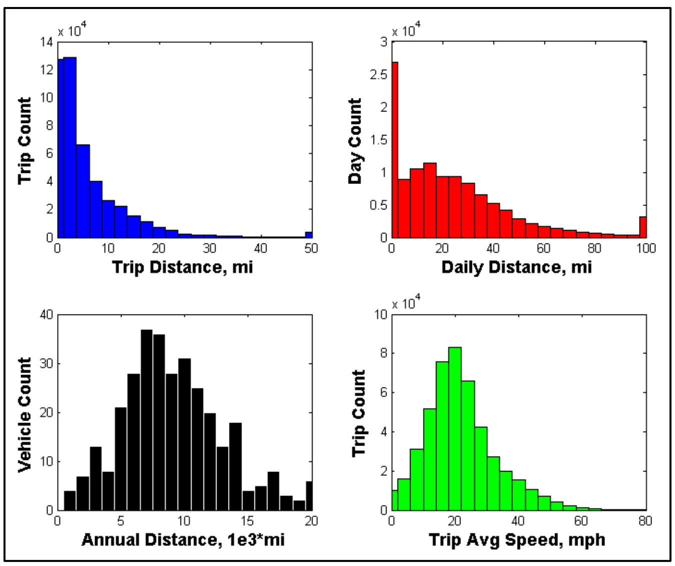

Figure 2. Trip distance, daily distance, annual distance, and trip average speed distributions for all 317 PSRC vehicle histories from the PSRC study.

We then filter these histories to those that accrued 8,000 miles or more over this one-year period to focus the simulation on higher mileage drivers. In Figure 3 we plot all 317 histories to show the utility factor (percent of CV miles achieved during BEV simulation) and the annual mileage they would achieve driving a 75-mile BEV without public charging. The black points to the upper left of the diagonal line represent the 137 drivers that completed fewer than 8,000 miles in a CV. These profiles are of lesser interest to this study as the low annual mileage implies they are unlikely to (1) benefit significantly from public EVSE, or (2) accumulate sufficient fuel savings to justify the upfront price premium of a BEV. The 91 drivers in the upper right corner of the plot (shown in blue) represent those that both completed more than 8,000 miles and achieved a utility factor greater than 80% in the 75-mile-range BEV (referred to as Profile Set A later in this study). Arguably, these drivers are well suited to driving such a BEV without public charging, but they are still included. The remaining 89 drivers (shown in red) are high-mileage drivers that achieve low utility factors with a 75-mile BEV, and thus drivers that could benefit significantly from range extension methods like public charging (referred to as Profile Set B later in this study).

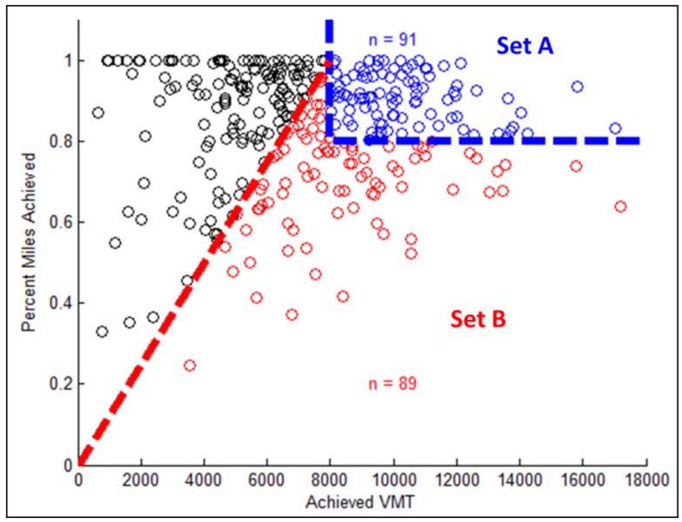

Figure 3. Simulated utility and achieved vehicle miles traveled (VMT) for PSRC travel histories in a 75-mile BEV.

A sample of the detailed spatial data utilized in this study is shown in Figure 4. This aerial view of a shopping center in urban Seattle includes markers indicating parked locations from all 365 days and 317 vehicles overlaid on satellite imagery. This map is an example of the relative accuracy of the spatial data contained in the PSRC dataset with parked locations from global positioning system devices clustered around and coinciding with painted parking stalls from satellite imagery.

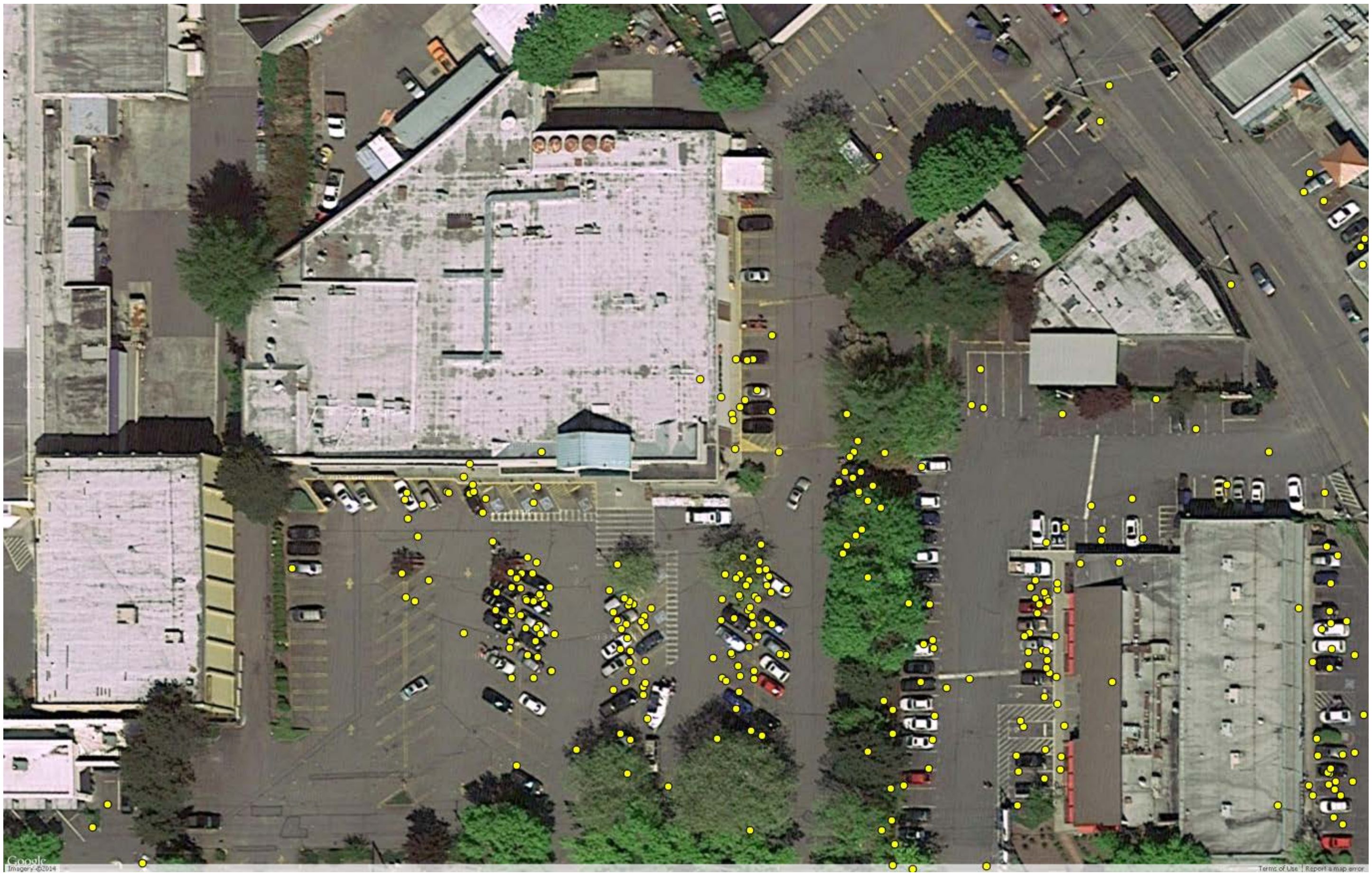

Figure 4. Aerial view of a shopping center in urban Seattle with markers indicating parked locations from all PSRC travel data overlaid on satellite imagery. (Google Maps credit: © 2014 Google, Map Data © 2014 Tele Atlas)

Driver Behavior

It is assumed that all drivers in this study operate BEVs with "normal" levels of driver aggression (25^{th} to 75^{th} percentile) as described in previous BLAST-V studies [7, 9].

For the purposes of making a go/no-go decision prior to the start of each tour, it is assumed that all drivers impose a minimum allowable SOC tolerance of 15% (approximately 11 miles for a 75-mile BEV) per the discussion above of BLAST-V's "Nominal Capabilities," which is to say that drivers will only elect to drive their BEV on tours where the estimated battery SOC is greater than 15% for the entire tour. This SOC tolerance provides a reasonable buffer in situations where simulated driving range turns out to be less than the pre-tour estimate.

Vehicle Performance

We employed a mid-size sedan with technology and performance levels anticipated for a 2020 model year vehicle. We utilized FASTSim (Future Automotive Systems Technology Simulator) [10] to simulate the vehicle response to the Urban Dynamometer Driving and Highway Fuel Economy Driving schedules, the results of which are weighted and combined per [11] to approximate the U.S. Environmental Protection Agency-rated range. We further employed FASTSim to simulate the vehicle's response to the National Renewable Energy Laboratory's DRIVE cycle to calculate the vehicle's real-world efficiency [9]. Note that within BLAST-V simulations, auxiliary loads for the vehicle's cabin heating, ventilation and air conditioning and battery thermal management system are added separately, and the efficiency computed from the DRIVE cycle is adjusted for the speed and distance of each trip. Vehicle parameters are given in Table 1.

Table 1. Parameters for simulated 75-mile BEV.

0-60 mph Acceleration	9 sec
Approximated U.S. Environmental Protection Agency-rated Range	75 miles
Battery Energy	22.1 kWh (100% usable)
Motor Power	106 kW
Vehicle Curb Weight	1,576 kg
Vehicle Efficiency	220 Wh/mi on DRIVE cycle (excludes auxiliary loads accounted for during BLAST-V simulations)

Battery Attributes

All battery electrical, thermal, and life calculations in the study employ a single-node battery model that assumes uniform response between all cells in the pack. Electrical modeling is done using a zero-order equivalent circuit approach with open circuit voltage and internal resistance parameters based on a lithium-ion cell with a nickel-cobalt-aluminum cathode and graphite anode. Thermal modeling considers battery response to ambient and cabin temperatures in the presence of an active battery cooling system. Life modeling is implemented via a physically justified and empirically fit system of equations for describing calendar- and cycling-induced resistance growth and capacity fade based on a thru-life nickel-cobalt-aluminum dataset. While battery degradation calculations are inclusive in this analysis, the duration of simulations (all one year long) and moderate climate (Seattle) resulted in a negligible impact on the results. For more extensive documentation on BLAST-V pack modeling approaches, please refer to [7].

Environmental Conditions

Seattle was selected for ambient temperature and solar irradiation input data as it is coincident with the PSRC travel data and represents a relatively moderate climate. Typical meteorological year data for Seattle is taken from [12] and illustrated in Figure 5.

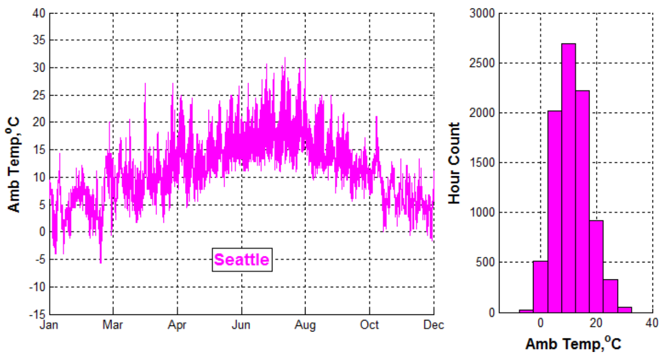

Figure 5. Ambient temperature data from Seattle, Washington.

Charging Infrastructure

For vehicle charging, we assumed a Level 2 charger (6.6 kW AC) is installed at each driver's home and used in an "opportunity" mode (i.e., whenever the driver is at home, the vehicle is plugged in and charging). Several public networks of Level 2 chargers are placed in the Seattle metropolitan area for simulation. The first deployment mimics existing Level 2 charger locations in the Seattle area, per the U.S. Department of Energy's Alternative Fuels Data Center [13] (sourced Jan 2014). Figure 6 shows the locations used to represent existing infrastructure.

Figure 7 shows maps of the two base layers used for locating synthetic rollouts of publically available EVSE. The map on the left consists of 33,477 unique locations based on all trip destinations from the PSRC dataset (referred to as Infr302). Infr302 provides an upper bound for the incremental BEV utility afforded by public charging as it makes Level 2 charging available everywhere a vehicle parks in the BLAST-V simulations. However, when considering that Seattle had fewer than 300 public charging stations as of January 2014, a deployment on the order of Infr302 is unlikely to be available any time soon.

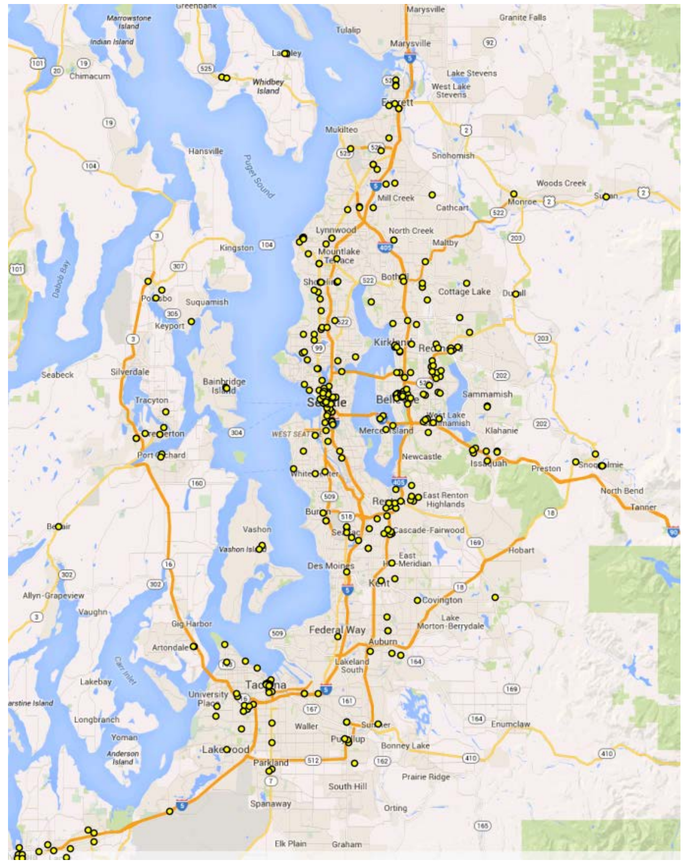

Figure 6. Existing Level 2 charger locations in the Seattle area (U.S. Department of Energy's Alternative Fuels Data Center, sourced Jan 2014). (Google Maps credit: © 2014 Google, Map Data © 2014 Tele Atlas)

This reality prompted the need to prioritize siting EVSE such that the most critical stations (in terms of incremental BEV utility) are located first. The most obvious prioritization method was to sort each unique location by the sum of vehicle dwell time (referred to as Infr302a). Unfortunately, this prioritization was clearly suboptimal as it potentially gave weight to stations with high amounts of dwell time on tours that were already within the single-charge range of the simulated BEV.

To address this bias, Infr302a was down selected to Infr402a (shown in the right half of Figure 7) using a baseline BLAST-V simulation with no public charging infrastructure to eliminate trip destinations from tours within the single-charge vehicle range. Infr402a was likely an improvement over Infr302a, but because it was still sorting based on dwell time, it was possibly skewing towards locations with relatively low amounts of electrical throughput. This prompted the creation of Infr402b, which sorted based on simulated electrical throughput from a BLAST-V simulation with all 11,578 stations from Infr402 available.

The final iteration resulted in Infr402c, which addressed the potential misalignment between all charging throughput and charging throughput that enables completion of long-distance tours. Infr402c was prioritized using an additional BLAST-V simulation in which all 11,578 stations from Infr402 were made available (as in Infr402b) with the condition that drivers only utilize public chargers as necessary to complete tours. Throughput from this simulation was summed by location and used to generate prioritization for Infr402c.

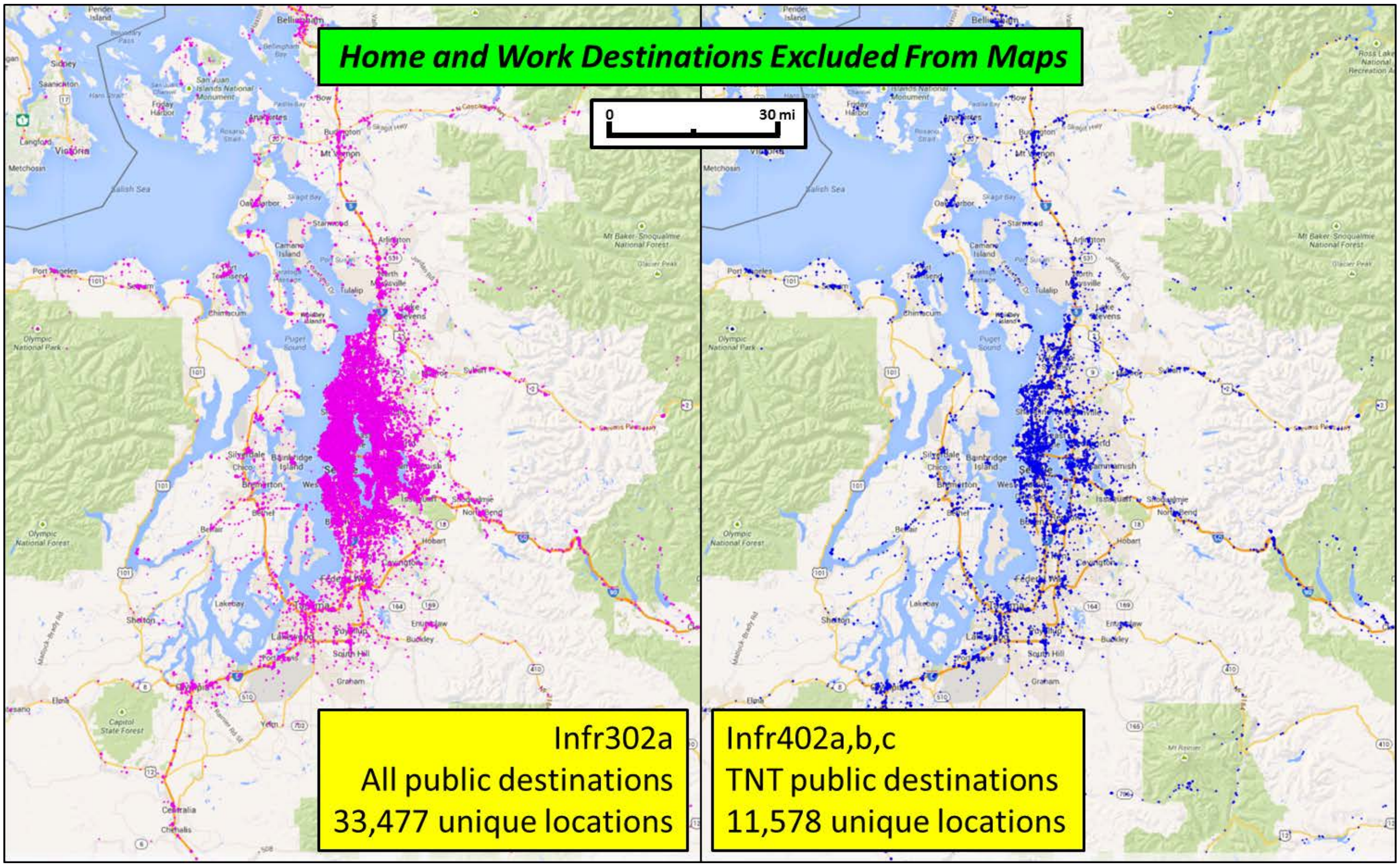

Figure 7. Unique public parked locations from all 317 PSRC vehicles (at left) and unique public parked locations from all 317 PSRC vehicles on tours not taken (TNT) in baseline simulation (at right). Exact trip destinations in map have been modified to mask precise locations as a privacy precaution. (Google Maps credit: © 2014 Google, Map Data © 2014 Tele Atlas)

In summary, the following Level 2 public charging station deployment/prioritization combinations were constructed for BLAST-V evaluation:

- **Infr302a:** All trip destinations ranked based on the sum of vehicle dwell time at each location.
- **Infr402a:** TNT (tours not taken) trip destinations ranked based on the sum of vehicle dwell time at each location.
- **Infr402b:** TNT trip destinations ranked based on the sum of station electrical throughput from BLAST-V simulation with all 11,578 stations available.
- **Infr402c:** TNT trip destinations ranked based on the sum of station electrical throughput from BLAST-V simulation with all 11,578 stations available, but where drivers only charge at public stations when necessary to complete tour.

Simulation Results

Although some parameter uncertainty exists in the underlying historical drive and climate data employed in this study, the main source of uncertainty is structural. The principal structural uncertainties include the approach to modeling human tour decisions, the method of computing vehicle energy consumption, and the battery performance and life models employed. Quantifying the level of uncertainty present in our modeling of human tour decisions is challenged by the need for large amounts of data on the real-world tour decisions of BEV drivers. The additional aspect of drivers changing tours in response to infrastructure is addressed in a parallel study [14].

The second factor, computation of vehicle energy consumption, is applied consistently across all scenarios herein. Thus, while it is expected to affect the absolute vehicle utilities calculated, it should not significantly affect the relative impacts of different public charging scenarios. Improving the accuracy of battery performance and life models to account for cell-to-cell variation within a pack and better ascertain the impacts of fast charging on battery wear is a major focus of a parallel study [15]. Despite these uncertainties, however, the following findings are telling as to the relative impact of public charging impact on overall BEV utility.

Vehicle to Station Proximity Tolerance

As discussed above, at the end of every non-home trip BLAST-V calculates the distance from the current parked location to the nearest public EVSE. It assumes the vehicle is plugged in if the calculated vehicle-to-station proximity is within some predefined tolerance. This logic assumes that drivers would be willing to adjust their parking behavior by up to some distance in order to utilize public EVSE. To better understand the impact the value of proximity tolerance has on simulated BEV utility, two infrastructure scenarios (existing and Infr402c), each with 281 public EVSE stations, were run in BLAST-V using a range of proximity tolerances. The results of this sensitivity analysis are presented in Figure 8. As expected, BEV utility shows a positive correlation with the proximity tolerance variable (drivers can better utilize public charging given a high level of flexibility with regard to where they park their vehicle). It is interesting to note the high level of sensitivity observed in scenario Infr402c when the proximity of the vehicle to a station is less than 500 feet.

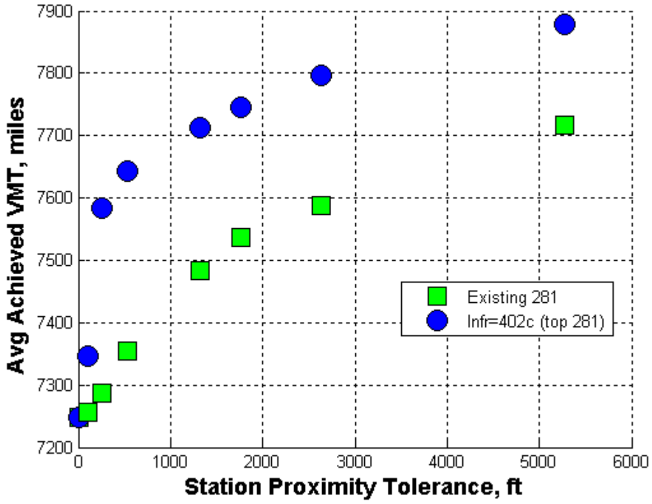

Figure 8. Averaged achieved BEV VMT for 281 stations cited using 1) existing locations and 2) citing algorithm 402c. Sensitivity to station proximity tolerance is explored (distance between original parked location and nearest EVSE to assume vehicle is plugged in during simulation).

Unfortunately, selecting a representative vehicle-to-station proximity tolerance for BLAST-V simulations is constrained by a lack of data in this area. Additionally, it is likely that this tolerance is non-uniform and variable with respect to destination. For example, travel to a single-family residential home would likely present a low tolerance for modifying the original parked location (parking at a public EVSE station and then walking to the original destination). However, public venues with large parking lots and several entry points would likely offer a great deal of flexibility (especially in cases where EVSE is located near the venue and reserved for plug-in vehicles). In light of these factors, a proximity tolerance of 528 feet (0.1 mile) is selected for the remainder of this analysis.

Existing Public Level 2 EVSE Scenario

Evaluation of the utility benefit afforded by existing Level 2 public charging requires the simulation of a baseline scenario with no public charging. The 317 simulated BEVs achieved an average of 7,236 miles in the baseline scenario out of an original average of 9,153 miles achieved in a CV (79.1% utility). Enabling 281 Level 2 charging stations in the Seattle area increased utility to 7,355 miles (80.4% utility). At first glance, a BEV utility increase of a little over 1% seems rather insignificant. What this number does not capture is the amount of electrical throughput provided (11.4% of all simulated electricity was sourced from public stations, a value that agrees well with the EV Project calculation that 15% of all charge events occur away from vehicle home locations [2]), potential psychological benefit of knowing that public charging is available if necessary, or benefits to plug-in hybrid electric vehicles with nominally shorter all-electric ranges. It also does not convey the fact that individual drivers and particular subsets of drivers accrued significantly greater benefit.

Ultimately, the effectiveness of any infrastructure scenario is difficult to assess independent of competing scenarios. To that end, four synthetic public Level 2 EVSE scenarios are presented to provide context and understand alternative planning approaches.

Synthetic Public Level 2 EVSE Scenarios

Figure 9 provides BEV utility values for each of the previously identified station prioritization methods. Simulation results are presented for each method in increments of 10 stations with prioritization determined by previously identified methods. In addition to the four utility curves resultant from synthetic public EVSE rollouts, a number of reference points are provided. Average utility from the original CV travel profiles is shown at 9,153 miles (100% utility). Average BEV utility, assuming no public charging, is shown at 7,236 miles (79.1% utility). Average BEV utility assuming ubiquitous public Level 2 charging (all 33,477 stations from Infr302) is shown at 8,069 miles (88.2% utility). Average BEV utility assuming existing public Level 2 charging (281 Seattle area stations) is shown at 7,355 miles (80.4% utility).

Figure 9 shows how station prioritization method Infr402c provides superior BEV utility across all station counts. By ranking potential charging stations using a combination of spatially resolved travel data and high-fidelity vehicle simulation, Infr402c provides the most incremental BEV utility on a per-station basis relative to alternative scenarios (including existing infrastructure deployment).

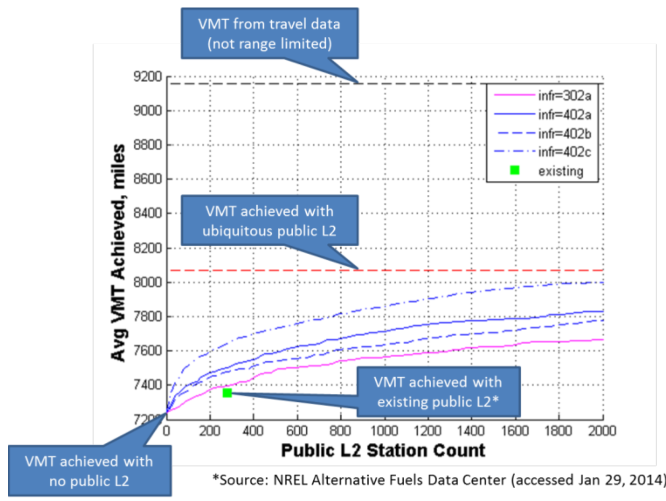

Figure 9. Average BEV VMT achieved relative to various public EVSE availability scenarios.

However, even method Infr402c requires a large volume of EVSE stations to approach the maximum potential of public charging. At 2,000 stations, under Infr402c the average simulated BEV utility is 7,998 miles (87.4% utility). To put this number of stations into perspective, consider that the Seattle metropolitan area (defined here as Snohomish, King, and Pierce counties) had 896 gasoline refueling stations as of 2011 [16].

Even in simulations where public Level 2 charging is made universally available (all 33,477 stations from Infr302), there remains an 11.8% shortfall in achieved BEV mileage. At first this may seem to be a puzzling conclusion until recalling the rigid implementation of travel data in BLAST-V. As driver travel histories are directly applied from real-world CVs to our simulated BEVs, there exists no margin for altering travel behavior to allow for extended charging events, mid-trip stops for charging, or a priori travel planning with vehicle range limitation in mind. While neglecting these very real human behavior considerations may result in underestimation of BEV utility relative to public charging availability, it is also very possible that many consumers will not be willing to adapt their travel behavior to accommodate the range and recharging limitation of a BEV.

BLAST-V is used to explore the tradeoff between travel behavior modification and BEV utility in a parallel study [14].

Thus far, we have explored all simulation results in aggregate across the 317 driving profiles. However, it is interesting to note relative differences in incremental utility afforded by public charging to different groups of driving profiles. Table 2 shows achieved utility for the simulated 75-mile BEV from three groups of driving profiles:

- **Full Set:** All 317 profiles
- **Profile Set A:** Drivers with over 8,000 miles of original travel and achieving at least 80% of those miles in the simulated 75-mile BEV
- **Profile Set B:** Drivers with over 8,000 miles of original travel and achieving less than 80% of those miles in the simulated 75-mile BEV.

Simulated utility results are shown in Table 2 with and without public charging available. Results with public charging are extracted from Infr402c (the most effective scenario at improving aggregate BEV utility) at the 1,000-station level.

Table 2. Average achieved BEV VMT with and without top 1,000 stations from Infr402c broken down by groups of driving profiles.

	Full Set	Profile Set A	Profile Set B
Profile count	317	91	89
Avg original VMT	9,153	11,474	12,201
Avg VMT achieved (no public stations)	7,236	10,085	8,071
Avg VMT achieved (1,000 public stations)	7,859	10,644	9,352
Avg utility factor (no public stations)	79%	88%	66%
Avg utility factor (1,000 public stations)	86%	93%	77%
Avg miles enabled by public stations	623	559	1,281

The group of drivers befitting most from public charging is Profile Set B, which experiences an average incremental utility of nearly 1,300 miles. However, even with 1,000 public charging stations available, Profile Set B is only able to achieve a utility factor of 77%. Alternatively, Profile Set A experiences an average incremental utility of less than 600 miles, but is able to achieve a utility factor of 93%. This finding raises an interesting question as to whom public charging is most valuable to: drivers who see the largest incremental utility as a result of public infrastructure, or drivers who come close to 100% with public infrastructure.

While the spatial upgrades to BLAST-V documented in this paper have primarily focused on quantifying BEV utility, there is also value to the infrastructure stakeholders in understanding how station placement and utilization are related. Figure 10 describes such a relationship by plotting the percent of total electrical throughput from public stations (averaged across all 317 driving profiles) against station availability. For example, for prioritization method 302a, at a 200-station deployment, 20% of all charging is done via public Level 2 stations. These statistics can be translated into economic indicators that could be used to estimate metrics such as payback period given a set of financial conditions (down payment, interest rate, etc.).

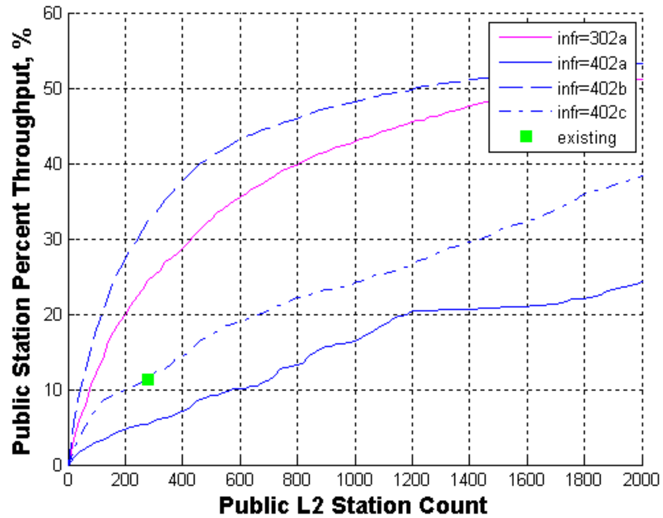

Figure 10. Percent of total simulated BEV energy originating from public Level 2 EVSE as a function of prioritization method and station count.

Examination of vehicle utility and station throughput curves highlights the conflicting objectives of consumers and EVSE operators in locating charging stations. For instance, Infr402c was shown to provide superior incremental BEV utility across all station counts; however, Infr402b can be seen to offer the highest throughput levels. Therefore, drivers would benefit more from chargers deployed per Infr402c, while EVSE operators that profit from increased throughput would benefit more from the same number of chargers deployed per Infr402b.

It should be noted the values in Figure 10 assume drivers plug in and utilize public EVSE whenever it is available and not just when it is necessary to complete a tour. While BLAST-V features the capability to limit public charging to an “as necessary” basis, the default in this analysis is to plug in and charge regardless of need (recall that Infr402c was designed using a simulation that employed “as necessary” charging and evaluated assuming vehicles are plugged in and charged whenever within the necessary proximity of a public station). In addition to making for a more direct analysis, it is unclear how public charging stations will price electricity going forward. Depending on the success of various business models, electricity at public charging stations may be priced at a premium to cover overhead expenses, priced lower than residential electricity to strategically entice parking, or some variant thereof.

As a final contrast between existing public charging infrastructure and our synthetic rollouts, consider the map of Seattle shown in Figure 11. This view of western Washington State shows the locations of 281 existing public Level 2 EVSE (green) alongside the 281 highest priority locations from Infr402c (blue). This figure shows that Infr402c was able to offer our simulated BEVs greater utility not by densely populating Seattle’s urban center, but rather by providing access to charging along Seattle’s perimeter, north and southbound along Interstate 5, throughout the Puget Sound, and into the mountainous rural eastern areas. While a large amount of vehicle dwell time does occur in Seattle’s urban center, tours through metropolitan Seattle are often within the single-charge range of our simulated BEV. By providing charging access in some of the more rural areas of Washington State, public charging could potentially enable a significant number of long-distance tours without the need for travel behavior modification.

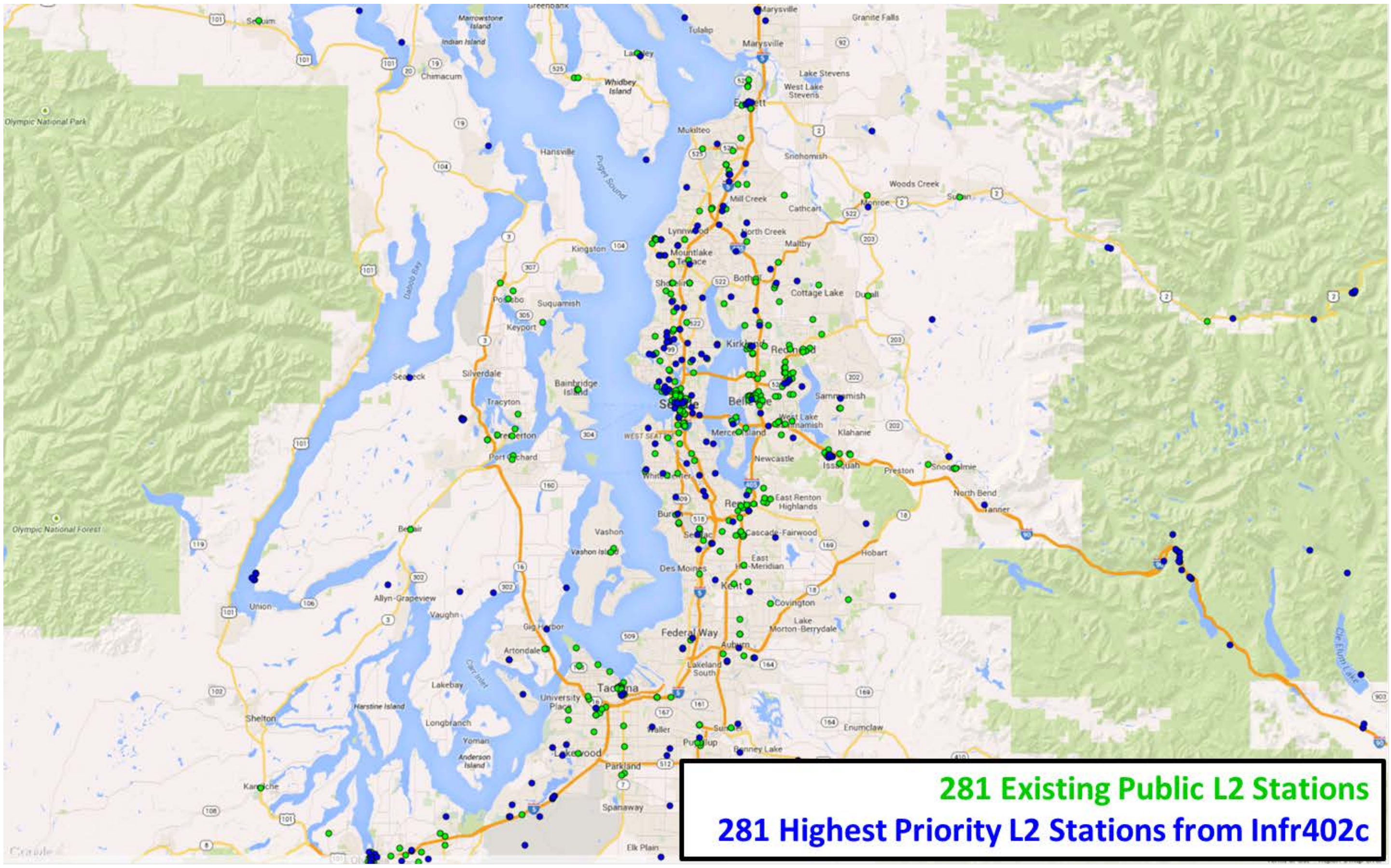

Figure 11. Google street map overlaid with locations of 281 existing public Level 2 charging stations and 281 highest priority stations from method Infr402c. (Google Maps credit: © 2014 Google, Map Data © 2014 Tele Atlas)

Summary

This paper has documented recent enhancements to the National Renewable Energy Laboratory's BLAST-V software that enable detailed spatial analysis of public charging benefits. Study of the Seattle metropolitan area using travel data from the PSRC has revealed that use of spatially resolved travel data in conjunction with advanced vehicle simulation can offer insights on how to locate public charging infrastructure to achieve specific objectives (such as BEV utility and station throughput). Exploration of a few simple EVSE deployment strategies has shown that significant gains in the amount of BEV utility provided by a discrete number of public chargers can be had when these strategies consider the interplay of BEV energy management with consumer travel patterns, rather than just vehicle dwell time at specific locations. It has also raised questions on metrics for quantifying the benefit of EVSE deployments to BEV drivers. In particular, how should the BEV community evaluate the relative importance of absolute increases in vehicle utility versus proximity to 100% utility?

In addition to showing the effects of different EVSE deployments on vehicle utility, this study has illustrated their effects on electricity throughput. It has highlighted a possible conflict between the motivations of BEV drivers and EVSE operators, as the EVSE deployment that appears to best enhance vehicle utility is not the same as that which maximizes electricity throughput, which may correlate with EVSE operator profits. Accordingly, development of incentives and business strategies for EVSE operators that align their motives with that of BEV drivers is encouraged.

Beyond these topics, however, these studies suggest that public charging availability alone may not be enough to allow average real-world drivers to approach the utility of their CV in an approximate 75-mile BEV without some level of travel behavior modification (i.e., extending public parked times, mid-trip stops for charging, BEV-specific tour planning). While BLAST-V is capable of addressing this topic in part (i.e., rerouting travel to available chargers), it is not capable of intelligently moving trips from one tour to another, altering the destinations of trips, or adjusting travel times, as real-world drivers may be prone to do when operating a range-limited BEV. Analyzing the effects of such behavior will require a greater understanding of both the nature of individual trips and human behavior.

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Definitions/Abbreviations

BEV	battery electric vehicle
BLAST-V	Battery Lifetime Analysis and Simulation Tool for Vehicles
CV	conventional vehicle
DRIVE	Drive-Cycle Rapid Investigation, Visualization, and Evaluation Analysis
EVSE	electric vehicle Supply equipment
FASTSim	Future Automotive Systems Technology Simulator
PSRC	Puget Sound Regional Council
SOC	state of charge
TNT	tour not taken
VMT	vehicle miles travelled