

# Feasibility of Battery Electric Pickup Trucks in a State Department of Transportation Fleet

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## Abstract

Vehicle manufacturers are beginning to introduce battery electric pickup trucks, with at least three models in production in the United States and at least six others announced. Unlike hybrid and plug-in hybrid vehicles which use batteries to supplement an internal combustion engine, battery electric vehicles are fully reliant on their batteries and have significantly shorter ranges, fewer refueling/recharging options, and may experience shorter ranges under towing, mountain driving, and temperature extremes. This study investigates real-world pickup truck usage data from a large state department of transportation to determine whether battery electric trucks can effectively replace trucks based on manufacturer stated range as well as early field tests of actual vehicle range under various speeds, idling scenarios, and weather conditions. Results found that 97% of pickup truck day trips could be completed on a standard range battery, and 99% on an extended range battery. Among tracked department of transportation fleet pickup trucks, 31% could be replaced by a standard range electric truck no change in operation. Up to 64% of the fleet could be replaced by an extended range electric truck with an extended range. Dynamically assigning long trips to dedicated conventional engine pickup trucks further could further reduce the number of non-electric trucks by half.

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## INTRODUCTION

In the second quarter of 2022, battery electric vehicles represented 5.6% of new vehicles sales in the United States, a new record (1). These vehicles, which rely on battery power only without the addition of an internal combustion engine, are expected to significantly reduce emissions even when considering the additional power needed to support them. Converting 25% of the U.S. vehicle fleet to fully electric vehicles is expected to produce 242 million fewer tons of CO<sub>2</sub> emissions, with 437 deaths avoided due to PM<sub>2.5</sub> reductions annually (2). Adopters may also benefit directly, as battery electric vehicles are estimated to save an average of USD \$4,500 in total cost of ownership when considering vehicle cost, maintenance, fueling, insurance, and depreciation (3).

Fleets represent a unique opportunity for vehicle electrification. Electric vehicles can be phased in slowly over time, allowing employees to adapt to the new technology. Because vehicles are housed at a central location overnight, facilities are incentivized to invest in high-speed charging infrastructure. Employees exposed to electric vehicle technology at work may be more comfortable in purchasing vehicles for personal use. State departments of transportation represent an especially attractive use case for electric trucks, given the high percentage of pickup trucks in their fleets as well as alignment with their missions of providing safe, efficient transportation.

A significant challenge for fleet owners is electric trucks shorter range and limited ability to charge remotely. Electric trucks on the market today have stated ranges of between 230 and 320 miles on a single charge (4, 5), with significant range reductions in cold weather or when towing (5, 6). High speed public charging stations can fully recharge a battery in under an hour, but charging stations are generally clustered in coastal urban areas and may not be as readily available for departments of transportation covering large rural areas.

Prior studies have investigated fleet adoption of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs). The city of Philadelphia found that they could electrify 44% of their vehicle fleet by 2030 while adhering to scheduled vehicle replacements (7). The greatest benefits were found from introducing BEV sedans into the fleet, followed by BEV pickup trucks. A pair of National Renewable Energy Laboratory (NREL) studies found that universities could replace 29% of their vehicle fleets with BEVs (8), while 46% of state fleets were good candidates for replacement (3). In both studies, battery electric pickup trucks were not yet on the market, and so pickup trucks were assumed to be replaceable with electric SUVs. Similar studies were conducted on taxis in Columbus, Ohio (9), Washington state fleet vehicles (10), and federal government fleet vehicles (11).

Other studies have modeled electric vehicle fleet operations, with focuses on smart charging (12), pricing schemes in a hybrid rideshare/transit deployment (13), shared autonomous electric vehicle energy demand (14), and optimal routing strategies (15). Technical challenges of electric vehicles that would apply to fleet management have also been investigated, including battery life cycle (16), ambient temperature's effect on range (17, 18), and charging infrastructure requirements for transit fleet operators (19).

This study represents the first effort to assess the suitability of battery electric pickup trucks for a department of transportation fleet using real-world vehicle logs from the Virginia Department of Transportation. This is a preliminary evaluation based on the best available albeit limited real-world data of electric truck performance. State transportation departments and similar public and private fleet operators have similar questions about battery electric truck capabilities, especially their estimated range in various conditions.

This study makes several contributions. The range of a major manufacturer's first electric truck are estimated based on ambient temperature and heating and air conditioning energy use in prior model year sedans, adjusted for larger, less efficient pickup trucks. These estimates are applied to real-world vehicle logs from a large state department of transportation to determine when, how, and to what extent battery electric pickup truck adoption is feasible. Finally, methods are developed to coordinate pickup truck use to cluster long trips with conventional engine trucks, thereby maximizing the market share of electric trucks without affecting fleet performance. The methods developed in this study can be easily adapted to different truck models with different capabilities and to vehicle fleets of various sizes and usage characteristics.

## **MATERIALS AND METHODS**

### **Electric Pickup Truck Selection and Characteristics**

There are three electric pickup trucks on the U.S. market as of July 20, 2022: the Rivian R1T, Hummer EV, and Ford F-150 Lightning (20). Six others have been announced: the Chevrolet Silverado EV, GMC Sierra EV, Tesla Cybertruck, Lordstown Endurance, Toyota Tacoma EV, and Canoo Pickup Truck (20). Of the models currently in production, the Rivian R1T is not available through the U.S. General Services Administration for procurement (21), making it difficult for state DOTs to order vehicles as many states use similar procurement mechanisms. The Hummer EV is available, but the Virginia Department of Transportation has no conventional Hummer pickup trucks in their fleet.

As a result, this analysis focused on the Ford F-150 Lightning Pro, referred to throughout as “the electric truck” for the remainder of the paper. Unveiled in 2021 and beginning production in April 2022, the F-150 Lightning has similar dimensions to prior year conventional F-150s (22). The Pro model was intended for purchase by large vehicle fleets and so has minimal add-on features. The starting price for the Pro model is US\$39,974 (23). By comparison, VDOT owns 68 conventional Ford F-150s and 130 F-250s, representing 16% and 32% of VDOT's total pickup truck fleet, respectively.

The electric truck comes in two battery configurations: the standard range with a 98 kWh battery and an EPA-estimated 230-mile range, and the extended range with a 131 kWh battery and an EPA-estimated 320-mile range (4).

Charging times vary based on the power source. A standard range 98 kWh battery can be charged from 15% to 100% in 13 hours using a standard NEMA 14-50 240 volt outlet. A similar outlet can charge the extended range battery in 19 hours. Installing specialized equipment such as the 80A Ford Charge Station Pro reduces charge time to 10 hours for standard range and 8 hours for extended range. (The shorter time for the extended range is because it uses two separate 55 kWh batteries which can be charged faster than the single 98 kWh battery with the 80A charger.) Level 3 fast charging is available at some public charging stations, with 150 kW stations providing 41 miles on standard range and 54 miles on extended range in 10 minutes (4).

The electric truck estimates range both at the beginning of the trip, and range is continuously updated throughout based on changing conditions. The driver selects a destination and route, and enters the dimensions of any towed trailer. Vehicle sensors measures the weight of the payload and trailer (24). The onboard navigation system adjusts expected range based on speeds, traffic, temperature, and gradient. The exact methodologies are proprietary, but users have reported a 50% reduction in range when towing a 6,000 lb trailer (25).

**VDOT Fleet Data**

The Virginia Department of Transportation (VDOT) owns 1,781 light duty vehicles such as vans, sports utility vehicles (SUVs) and pickup trucks. Passenger cars and sedans are not owned by VDOT but are instead leased through the Department of General Services. Of the 1,781 light duty vehicles, 1,248 (70%) are pickup trucks. Of the trucks, 899 (72%) are ¾ ton, e.g., Ford F-250 and Chevy Silverado 2500. Another 322 (26%) are ¼ ton, e.g., Ford F-150 and Chevy Silverado 1500. The remaining 27 (2%) pickup trucks are compact, e.g., Nissan Frontier.

**VDOT CalAmp Data**

The Virginia Department of Transportation (VDOT) has begun outfitting state vehicles with CalAmp vehicle trackers, which record information about daily trips. CalAmp is a telematics company, producing technology to track vehicle fleet information via GPS and the vehicles own diagnostics transmitted daily via cellular networks. CalAmp trackers record vehicle information over the course of a full day of travel including the date, mileage, moving time, stopped time, idling time, total engine hours, and fuel economy. The dataset also contains information about the vehicles including vehicle make, model, year, odometer reading, VIN, and which district the vehicle is assigned to at the Department of Transportation. This research focuses on data from CalAmp vehicle trackers that have been installed on pickup trucks in the VDOT fleet. These devices have primarily been installed on pickup trucks in Richmond and Fredericksburg Districts, and to a lesser extent on pickup trucks in Staunton, Salem, and Northern Virginia Districts. One year of CalAmp data on VDOT pickup trucks from June 1, 2021 through May 31, 2022 was downloaded. Data was cleaned by removing days which were logged but contained no travel data. Additionally, a small subset of data was removed which contained data about miles traveled by the vehicle but showed zero time was spent moving as this was judged to be unreliable.

An outlier screening was performed on three variables: Engine hours (referring to the time the engine was running), Moving Speed (calculated from Moving Time and Distance which both contain extreme outliers), and Fuel Economy (only a small portion of the dataset contains fuel economy data). These variables were selected because each contained extreme outliers which significantly skewed statistics about the dataset expected to be necessary for analysis. A conservative 3x standard deviation beyond the mean was used to remove outliers for Engine Hours, Moving Speed, and Fuel Economy. This was found to be insufficient for Moving Speed and Fuel Economy as the outliers present in the dataset were so extreme as to skew the standard deviation. As a result, Moving Speed was trimmed to remove values greater than 90 mph and Fuel Economy was trimmed to remove values greater than 30 mpg (based on the maximum highway fuel economy of pickup trucks in the dataset). Summary statistics for Engine Hours, Moving Speed, and Fuel Economy before and after outlier removal are shown in Table 1. A total of 740 vehicle-days of travel were removed during the outlier analysis.

**Table 1 Outlier Analysis Impacts**

		<b>Count</b>	<b>Maximum</b>	<b>Average</b>	<b>Median</b>	<b>St Dev</b>
Before Outlier Analysis	Engine Hours Dec (hrs)	60834	768.7	2.7	2.2	5.3
	Moving Speed (mph)	60834	723600.0	142.2	33.0	4852.8
	Fuel Efficiency (mpg)	2210	36675.8	222.1	5.9	1281.8
After Outlier Analysis	Engine Hours Dec (hrs)	60095	18.3	2.6	2.3	1.9
	Moving Speed (mph)	60095	89.9	32.4	32.9	11.7
	Fuel Efficiency (mpg)	1836	30.0	7.0	5.3	5.3

## Range Estimation

Vehicle fuel economy in the United States is measured by using a dynamometer operating under different cycles meant to represent various driving conditions (26). This process was developed by Environmental Protection Agency (EPA) and is referred to as a vehicle’s EPA-estimated mileage or range.

The electric truck in this study has an EPA-estimated range of 230 miles when equipped with a standard range 98 kWh battery, and 320 miles when equipped with an extended range 131 kWh battery. Energy use is therefore approximately 0.42 kWh/mile. The EPA does not list separate highway and city energy use for this truck, but video field tests conducted by product reviewers have shown rates of 0.47–0.50 kWh/mile on freeways in cool weather using larger, less efficient tires (27, 28).

Electric vehicles are known to have reduced ranges under extreme high or low temperatures (29). Extreme temperatures affect battery output in two ways: energy recuperation is intentionally limited to reducing premature battery aging, and battery power must be diverted towards heating, ventilation, and air conditioning (HVAC) for the vehicle cabin (6). In order to isolate these effects, the American Automobile Association conducted a study on five battery electric vehicles on a dynamometer in 20°F, 75°F, and 95°F (-7°C, 24°C, and 35°C) both with and without heating and air conditioning (30). Two of tested vehicles used heat pumps, while five used the less efficient resistance heating also used in the Ford F-150 Lightning. They found a 41% reduction in range when using HVAC in cold weather, and a 17% reduction in hot weather (30). These proportions would not directly translate to a pickup truck, however, for two reasons: the pickup truck’s size and weight require a greater amount of energy to travel at speed without requiring a proportional increase in HVAC energy requirements, and the truck has a larger cabin than a typical sedan thus requiring more energy for HVAC.

To estimate the energy use of an electric truck, the energy usage of the sedans at different speeds both with and without HVAC were compared. These data are shown in Table 2.

**Table 2 Estimated Energy Use by Ambient Temperature and HVAC**

Measurement / Estimate	Temperature			Units
	20°F	75°F	95°F	
Sedan average energy use without HVAC (30)	0.297	0.288	0.296	kWh/mi
Sedan average energy use with HVAC (30)	0.376	NA	0.316	kWh/mi
Sedan energy use, HVAC-only	0.080	0	0.020	kWh/mi
Electric Truck without HVAC (Estimated)	0.431	0.420	0.431	kWh/mi
Electric Truck with HVAC (Estimated)	0.565	NA	0.464	kWh/mi
Electric Truck – HVAC only (per mile)	0.133	0	0.033	kWh/mi
Electric Truck – HVAC only (idling)	0.120	0.005	0.030	kWh/minute

These data were calculated as follows. First, an adjustment factor to account for the effect of ambient temperature on battery capacity use was calculated by dividing the *Sedan average energy use w/o HVAC* at extreme temperatures ( $E_{1,T,C=0}$ ) by the same measurement at moderate temperatures ( $E_{1,T=75,C=0}$ ). In this example, subscript 1 represents the sedan with known energy use and subscript 2 represents the truck.

$$F_{2,T,C=0} = \frac{E_{1,T,C=0}}{E_{1,T=75,C=0}}$$

Where

- $F$  = adjustment factor
- $E$  = energy
- $T$  = ambient temperature (F)
- $C$  = HVAC status (1 = on, 0 = off)
- $V$  = cubic volume of cabin

The known kWh/mi of the electric truck calculated from the EPA-estimated range and battery capacity of 0.420 kWh/mi was multiplied by the adjustment ratios to obtain energy usage without HVAC.

$$E_{2,T,C=0} = E_{2,T=75,C=0}(F_{2,T,C=0})$$

To determine energy usage with HVAC, the energy required to heat or cool a sedan cabin must be measured. An adjustment factor can be calculated from the measured from the AAA data by subtracting the *Sedan average energy use w/o HVAC* from the *Sedan average energy use w/ HVAC* and multiplying by the proportional difference in cabin volume between subject vehicle and sedan.

$$F_{2,T,C=1} = (E_{1,T,C=1} - E_{1,T,C=0}) \frac{V_2}{V_1}$$

While surface area and heat transfer resistance are also important factors for determining cabin heating demand, cubic volume is used as a surrogate measure as this is often reported by manufacturers. The Tesla Model 3, the best-selling electric sedan in 2021 (31), has 110 ft<sup>3</sup> of interior space (32), while the electric truck has estimated 184 ft<sup>3</sup> based on headroom, seat height, shoulder room, and leg room measurements (4). It should therefore require approximately 184/110 = 1.67 times more energy to heat or cool the electric truck.

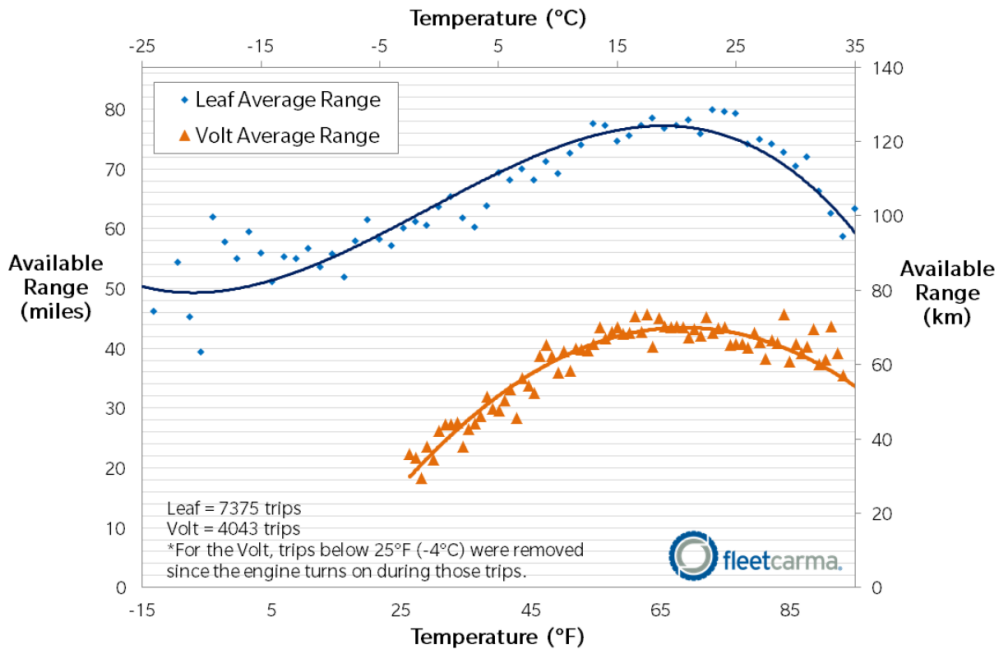
Truck energy usage per mile with HVAC could then be calculated by multiplying truck energy use at 75 degrees without HVAC by both adjustment factors.

$$E_{2,T,C=1} = E_{2,T=75,C=0}(F_{2,T,C=0})(F_{2,T,C=1})$$

Fleet vehicles often spend significant amounts of time idling, either in a work zone or while conducting field work. The electric truck was assumed to require only the energy required for HVAC while idling. The electric likely has other draws on power such as dome lights, headlights, radio, etc., but for this study these are assumed to require no more than 0.005 kWh/minute. Converting kWh/mi to kWh/minute is done by multiplying *Electric Truck – HVAC only (per mile)* by 48.3 mi/hr—the average vehicle speed in the EPA Highway Fuel Economy Driving Schedule (26) from which the sedan energy use was taken—and divided by 60 minutes/hour.

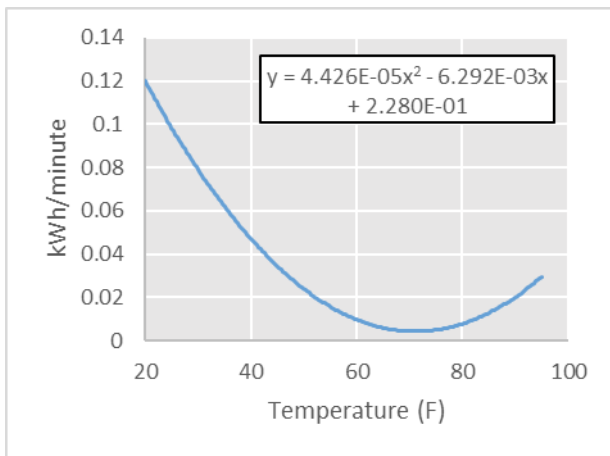
A FleetCarma study of 7,375 Nissan Leaf trips and 4,043 Chevy Bolt trips in Canada across various temperatures found that range could be modeled by a second or third order

polynomial temperature function, as shown in Figure 1 (33). These data did not separate the effects of ambient temperature and HVAC use on vehicle range but do establish that the relationship between temperature and energy use is nonlinear. It should be noted that a heat pump is an optional upgrade on the Nissan Leaf and is unavailable for the Chevy Bolt at the time these tests were conducted. The study does not state whether the tested Leaf was equipped with a heat pump. Change in vehicle range may therefore differ significantly for electric vehicles equipped with more efficient heat pumps.

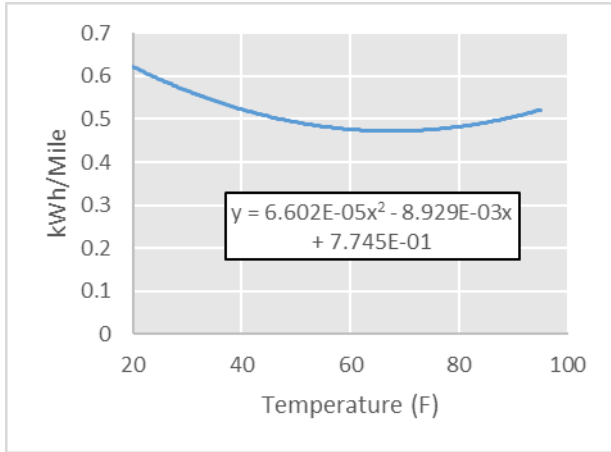


**Figure 1 Relationship between Temperature and Range for Nissan Leaf and Chevy Volt from FleetCarma Study, Reproduced from (33)**

Based on estimated energy use at three temperatures in Table 2, a simple second order polynomial function was fitted to the estimated data in order to predict energy use between the point temperatures in Table 2. These functions are shown in Figures 2 and 3.



**Figure 2 Estimate of Electric Truck Energy Use vs. Temperature While Idling**



**Figure 3 Estimate of Electric Truck Energy Use vs. Temperature While Moving**

The equations for energy use were applied to vehicles in the VDOT fleet using miles traveled and idling time per day (two variables present in the VDOT CalAmp vehicle database). Daily average temperatures were obtained from weather stations via the National Climatic Data Center at the United States National Oceanic and Atmospheric Administration (34).

## RESULTS

### Electric Eligible Trips

In this paper, the term “trip” will be used to refer to the total travel by a single vehicle over the course of an entire day, even if this total daily travel is composed of several discrete segments. For example, the total travel from a VDOT facility to a job site, then to any intermediate stops, and then back to the home facility would be considered one trip, even if then vehicle has multiple stops where the vehicle is turned off over the course of the day. The previously described equations to calculate truck energy use while moving or idling based on temperature were applied to the CalAmp fleet dataset. This step was taken to determine how many kWh would be required by an electric truck to complete the recorded daily trip, and determine whether or not the energy would be within the capabilities of an electric truck. This analysis is limited in that some factors that would impact electricity usage were not considered, such as grade, towing, and external power draws on the vehicle (such as truck mounted changeable message signs). It was found that the vast majority of daily trips in the dataset could be made by an electric truck. Across all trips by CalAmp equipped vehicles taken in the past year, over 97.4% of them could be completed by an electric truck with standard range (98 kWh). Additionally, 99.4% of the trips could be completed by an electric truck with extended range (131 kWh). Minor temperature impacts were observed, notably for colder months. For trips taken in January, 91.5% of trips fell under the 98 kWh trip range, and 96.9% of trips fell under the 131 kWh range. VDOT fleet vehicles are distributed across the state, as are the trips exceeding an electric truck range. Therefore individual truck data must be reviewed to understand the spatial spread of energy intensive trips and which trucks may be eligible for replacement.

### Electric Eligible Trucks

As the trips ineligible for electric truck replacement are distributed across the Commonwealth, individual vehicle characteristics are reviewed to determine potential for electric truck

replacement. Table 3 summarizes characteristics and trip profiles of 403 pickup trucks in the VDOT CalAmp fleet dataset. Although 405 pickup trucks are present in the dataset, two were excluded from this summary because they were moved between districts multiple times during the one year data time frame. Columns distinguish which VDOT district the trucks belong to (Fredericksburg, Northern Virginia, Richmond, Salem, or Staunton). Northern Virginia borders Washington D.C. and is highly urbanized. Richmond and Fredericksburg are located in central Virginia and also contain urban regions. Staunton and Salem districts are in western Virginia and are more mountainous and more rural than the other three districts. Of the 403 pickup trucks, 126 (31%) vehicles never recorded a trip exceeding 98 kWh (the range of the electric truck). Additionally, 259 (64%) vehicles never recorded a trip exceeding 131 kWh (the extended range of the electric truck). These pickup trucks can be readily replaced with an electric truck. Of the pickup trucks that did exceed the electric truck range, the majority exceeded that range less than once a month.

**Table 3 Trip Characteristics of Vehicles in Each District**

Vehicle Trip Electricity Usage	All districts	Fredericksburg	Northern Virginia	Richmond	Salem	Staunton
Vehicles ≤ 98 kWh for all trips	126 (31%)	27 (21%)	2 (67%)	70 (35%)	12 (50%)	15 (31%)
Vehicles with 0-1 trip >98 per month	248 (62%)	91 (72%)	1 (33%)	120 (60%)	9 (38%)	27 (55%)
Vehicles with 1-2 trips >98 per month	18 (4%)	6 (5%)	0 (0%)	4 (2%)	3 (13%)	5 (10%)
Vehicles with 2-3 trips >98 per month	6 (1%)	1 (1%)	0 (0%)	3 (2%)	0 (0%)	2 (4%)
Vehicles with 3+ trips >98 per month	5 (1%)	2 (2%)	0 (0%)	3 (2%)	0 (0%)	0 (0%)
Total Vehicles	403 (100%)	127	3 (100%)	200 (100%)	24 (100%)	49 (100%)
Vehicles ≤ 131 kWh for all trips	259 (64%)	74 (58%)	3 (100%)	132 (66%)	17 (71%)	33 (67%)
Vehicles with 0-1 trip >131 per month	141 (35%)	52 (41%)	0 (0%)	66 (33%)	7 (29%)	16 (33%)
Vehicles with 1-2 trips >131 per month	2 (.5%)	0 (0%)	0 (0%)	2 (1%)	0 (0%)	0 (0%)
Vehicles with 2-3 trips >131 per month	1 (.2%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Total Vehicles	403 (100%)	127 (100%)	3 (100%)	200 (100%)	24 (100%)	49 (100%)

**Maximizing Electric Eligible Trucks**

The number of pickup trucks eligible for EV replacement may be increased if longer trips are reserved for specific vehicles. For example, if a VDOT residency is assigned three pickup trucks, which are all occasionally used for energy intensive trips, it may appear that none of those vehicles are eligible for replacement. However, if these trips all occur on different days, one conventional pickup truck may be relegated for extended trips, leaving lower energy trips for the electric trucks. To determine whether this may apply to VDOT fleet data, office and residency locations in Richmond and Fredericksburg were reviewed, as more data is available for the fleet in these districts, lending itself to more reliable results. Additionally, because of the nature of the CalAmp equipped VDOT fleet, more vehicles were added to the dataset over the course of the one year of data acquired. The most recent month of data (May 2022) was used for this analysis to maximize the number of vehicles present in the dataset.

**Table 4 Trip and Vehicle Information for Fredericksburg and Richmond Districts in May 2022**

District	Residency / Office	Number of Trips	Number of Trips >98 kWh	Number of Vehicles Used	Number of Vehicles Used for Trips>98 kWh	Conventional Pickup Trucks Required
Fredericksburg District	Fredericksburg District Office	336	11	26	5 (19%)	2 (8%)
	Saluda Residency	410	9	28	5 (18%)	2 (7%)
	Northern Neck Residency	288	5	22	4 (18%)	1 (5%)
	Fredericksburg Residency	614	2	37	2 (5%)	1 (3%)
Richmond District	Richmond District Office	832	14	78	9 (12%)	4 (5%)
	Richmond Central Region Operations	160	12	13	3 (23%)	2 (15%)
	South Hill Residency	370	9	22	4 (18%)	4 (18%)
	Richmond Interstate Maintenance Office	40	5	3	1 (33%)	1 (33%)
	Chesterfield Residency	465	3	30	3 (10%)	1 (3%)
	Ashland Residency	545	2	34	2 (6%)	1 (3%)
	Petersburg Residency	189	1	14	1 (7%)	1 (7%)
	Richmond District Spares	6	0	2	0 (0%)	0 (0%)
Total		4255	73	309	39 (13%)	20 (6%)

Table 4 shows the residency and office locations within Fredericksburg and Richmond Districts, the number of recorded trips taken in the month of May, the number of those trips that exceeded the 98 kWh electric pickup truck threshold, the number of unique vehicles which made trips in May, and the number of unique vehicles used for the 98+ kWh trips in May. The 98+ kWh trips were reviewed to determine whether trips occurred on the same day, thus requiring conventional vehicles for each of those trips. The maximum number of overlapping trips dictates the number of conventional pickup trucks needed in that location (shown in the last column). If feasible to delegate 98+ kWh trips to specific conventional vehicles, the number of conventional trucks needed can be minimized. As seen in Table 4, intentionally delegating longer trips to conventional pickup trucks decreased the required conventional pickup truck portion of the fleet across both districts from 13% to 6%, allowing for 19 more electric trucks. A more conservative approach could stipulate that in locations where only one conventional pickup truck is needed to complete the expected trips greater than 98 kWh, two vehicles be required in case one vehicle is undergoing maintenance. Locations where no conventional pickup trucks were needed to complete trips during the month of May could be required to have one conventional vehicle available in case of rare high electric intensive trips. If approached this way, intentionally delegating longer trips to conventional pickup trucks would still decrease the required conventional pickup truck portion of the fleet in Richmond and Fredericksburg from 13% to 9%, and allow for 12 more electric trucks.

## CONCLUSIONS AND DISCUSSION

This study provides a first effort assessing electric pickup truck suitability for a department of transportation fleet. A state department of transportation fleet represents a unique case study due

to the large vehicle pool and the variety of vehicle use cases. Gradual turnover of the fleet as conventional vehicles age out allows for a steady incorporation of electric vehicles while allowing time for adjustment to change. Novel contributions include the application of ambient air temperature, heating use, and air conditioning use to electric pickup truck efficiency using real-world state department of transportation trip logs. Methods are developed to illustrate pickup trucks which may be readily replaced with electric trucks, and how to minimize conventional truck usage in the fleet.

In extreme temperatures electric vehicle batteries operate less efficiently and additional energy is diverted to heating and cooling of the cabin. This necessitates the adjustment of EPA-estimated ranges for ambient air temperature. Using data from an AAA report on HVAC impacts on electric vehicle range, models were developed to approximate the kWh/min of an electric truck while idling and kWh/mile of an electric truck while driving. These models were then applied to a dataset of CalAmp equipped Virginia Department of Transportation pickup trucks to determine vehicles eligible for electric truck replacement.

Using this unique source of department of transportation fleet data it was determined that the majority of trips taken by the fleet during the one year time frame could be accomplished by an electric truck. Across all trips in the one year dataset, over 97% could be completed by an electric truck with standard range (98 kWh) and over 99% could be completed by an electric truck with extended range (131 kWh). The small percentage of trips exceeding electric truck capabilities are spread out among vehicles and among districts. Upon analyzing individual truck data of the 403 pickup trucks reviewed, 126 (31%) vehicles never recorded a trip exceeding the range of the electric truck. Additionally, 259 (64%) vehicles never recorded a trip exceeding the extended range of the electric truck. These vehicles could be immediately replaced with an electric vehicle with no change to usage characteristics. A subset of the data was reviewed for the possibility of delegating conventional vehicles to electric intensive trips. Richmond and Fredericksburg districts for the month of May were chosen to capture a time frame and locations which have the highest percentage of vehicles equipped with CalAmp data trackers. Looking at this subset of the data it was found that 13% of vehicles were used for trips exceeding 98 kWh. With a concerted effort to designate conventional vehicles to electric intensity trips, only 6% of the fleet would be required to be conventional vehicles which can exceed 98 kWh trips.

This research serves as a useful case study incorporating electric pickup trucks into a state department of transportation fleet. It represents a preliminary feasibility study of how electric trucks may function in a Department of Transportation fleet based on limited real-world data on factors that impact vehicle range. Future work may expand this analysis to include factors such as changes in range due to mountainous vs. level terrain, towing, and external power draws (signage). Such additions would increase understanding of electric truck potential in department of transportation fleets. Research may also attempt to anticipate the effect switching from resistance heating found on the 2022 F-150 Lightning to more efficient heat pumps, common on many new electric vehicles (35).

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