Demonstration and Evaluation of U.S. Postal Service Electric Mail Delivery Vehicles

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I. INTRODUCTION

In December 1998 the Delivery and Customer Services Equipment Engineering division of the United States Postal Service (USPS) issued Specification USPS-E-PURC for the procurement of six Pilot Model [electric] vehicles “for examination and testing within the time frame specified by the Contraction Officer (CO), to prove that the production methods will produce methods will produce vehicles that meet the requirements specified herein”.

On December 22, 1999 the USPS announced that Ford had been selected to build the first 500 EVs of the demonstration program.

In April, 2000, the USPS and South Coast Air Quality Management District (AQMD) recognized Southern California Edison’s technical leadership position in the EV field and recommended that Baseline Performance and Accelerated Reliability Tests be performed at SCE’s Electric Vehicle Technical Center (EVTC) in Pomona, California, with oversight of the Department of Energy (DOE) Field Operations Program.

Under the terms of AQMD contract No. 00192, awarded on July 28th, 2000, SCE was to perform the following tasks:

- Task 1 – Baseline Performance Test Procedures Evaluation and Modification
- Task 2 – Accelerated Reliability Test Procedures Evaluation and Modification
- Task 3 – Conduct Baseline Performance Tests on two EVs
- Task 4 – Conduct Accelerated Reliability Tests on two EVs

Tasks number 1 and 2 were completed on August 10, 2000 when revision 0 of the Baseline Performance and Accelerated Reliability test Procedures were issued and forwarded to the USPS.

Tasks number 3 and 4 started in late August when SCE received USPS approval to operate the four vehicles delivered to the EVTC on July 5, 2000.

Task 3 was completed on November 15th of 2000.

This quarterly progress report completes the documentation of Baseline Test results and presents the progress to date on the Reliability Tests as of December, 2000.

II. TEST RESULTS TO DATE

Baseline Test Results

Dynamometer Testing

Dynamometer testing was performed at the Mercedes Emissions Testing Facility in Long Beach, California. This test site was chosen because it offered a four-wheel dynamometer, which was necessary in order for the vehicle's anti-lock braking system (ABS) to operate properly. Without tire rotation on the front wheels, the vehicle's regenerative braking does not function due to the ABS system sensing a loss of traction. The figure below shows one of four wheels on top of a 48-inch roller of an AVL/Real Time Instruments four-wheel drive electric inertia dynamometer.

Figure 1 – 48-inch Roller of an AVL/Real Time Instrument's Electric Dynamometer

Dynamometer Specifications

- 10,000 lb maximum inertia
- 200 Horse Power Maximum
- 1150 lb torque up to 65 mph (continuous)
- Maximum torque can be increased by 50% for 60 seconds

Gradeability Testing

Gradeability tests were simulated on the four-wheel dynamometer by adjusting the tractive force produced by the rollers. The purpose of these tests was to determine the maximum grade that the vehicles could overcome while loaded at maximum payload and the maximum speeds that the vehicles could acquire on a 2.5%, 3%, 6% and 20% grade. The USPS requirements state that the vehicles should be capable of starting and ascending a 25% grade at maximum payload, capable of reaching a speed of 55 mph on a 3% grade, capable of reaching a speed of 45 mph on a 6% grade and capable of reaching a speed of 10 mph on a 20% grade.

The gradeability limit was determined by setting the dynamometer at a set speed of 1 mph and measuring the maximum tractive force produced by the vehicle while at full throttle. Equation 1 below was used to obtain the maximum theoretical grade that the vehicle could overcome while driving at 1 mph. Table 1, below, summarizes the gradeability requirements and results. Figures 2 and 3 on the following page illustrate these findings.

$$Percent\ Gradeability\ Limit = 100\tan\left(\sin^{-1}\frac{P}{W}\right) \qquad \text{Equation 1}$$

Where P= Measured traction force, lb
W=Curb weight plus maximum payload, lb (6150 lb used for testing)

Table 1 – Gradeability Test Results

Test	USPS Requirements	Vehicle #3	Vehicle #4
Speed at 2.5% Grade	N/A	58.1 mph	58.5 mph
Speed at 3% Grade	55 mph	56.2 mph	56.3 mph
Speed at 6% Grade	45 mph	47.7 mph	47.1 mph
Speed at 20% Grade	10 mph	20.9 mph	22.3 mph
Gradeability Limit	25%	26.2%	26.6%

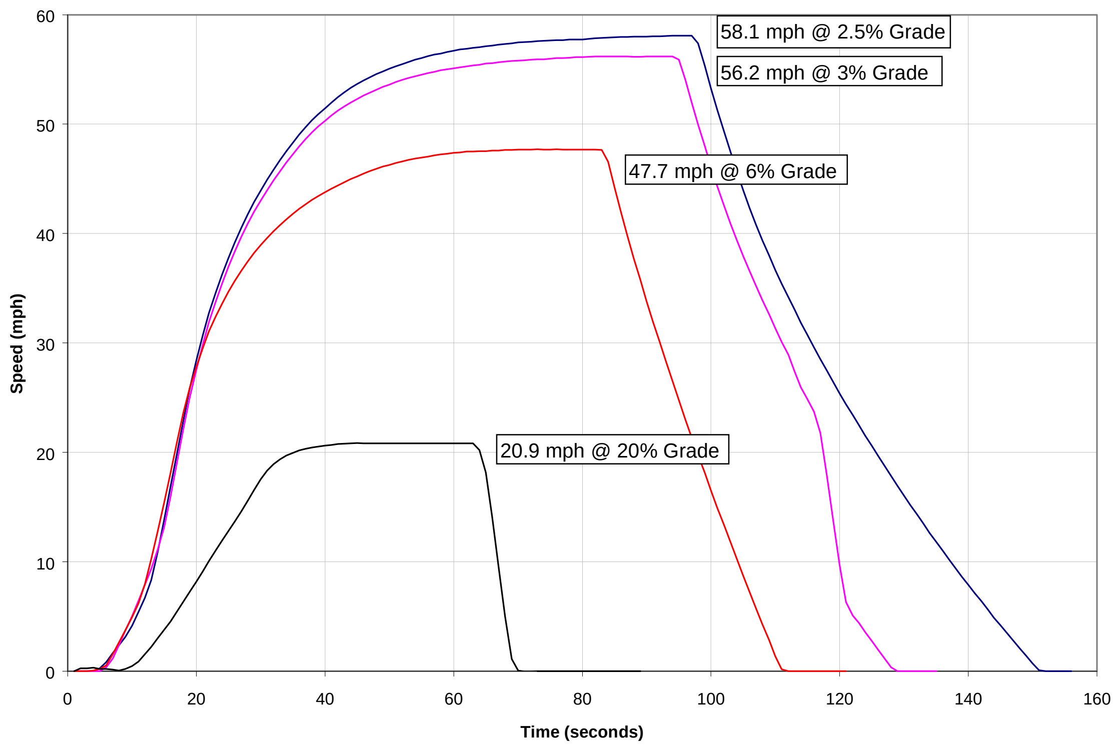

Figure 2 – Maximum Speed at Percent Grade for Vehicle #3

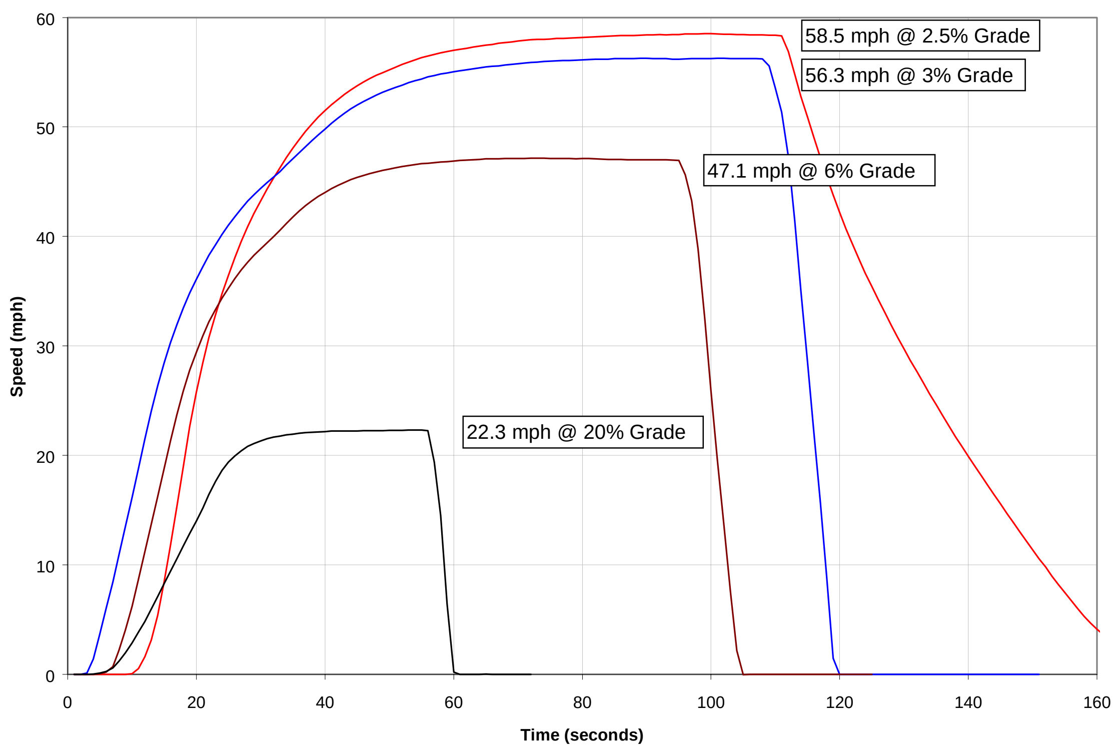

Figure 3 – Maximum Speed at Percent Grade for Vehicle #4

The results in the table and figures show that the vehicles meet and exceed the gradeability requirements of the USPS. These are important tests that prove that these vehicles can maintain a set speed at low to substantially high percent grades.

The maximum tractive force was also determined at vehicle speeds of 10 mph, 45 mph and 55 mph. The results obtained from these tests can be used along with equation 1 to determine the maximum grade that can be overcome. The table below shows the maximum tractive force along with the percent grade that the vehicle can overcome.

Table 2 – Gradeability as a Function of Maximum Tractive Force

	Test	Speed mph	Max Tractive Force, lb	USPS Requirements	Calculated % Grade
Vehicle #3	10 mph	10.3	1552.9	20%	26.1%
	45 mph	44.8	585.4	6%	9.6%
	55 mph	54.93	428.2	3%	7.0%
Vehicle #4	10 mph	10.4	1580.4	20%	26.6%
	45 mph	44.8	574.4	6%	9.4%
	55 mph	54.9	411.7	3%	6.7%

Dynamometer Range Testing

Range testing was performed in accordance to the Society of Automotive Engineer's (SAE J1634) recommended procedures for electric vehicle energy consumption and range testing. The average of two range tests was used to determine the overall range of each vehicle. The vehicles were loaded at maximum payload during all range tests. Tire pressure was set at 35 psi, as recommended by Ford.

The combined dynamometer range test cycle consists of two EPA Urban Driving Schedules (UDS) followed by two Highway Fuel Economy Test Procedure (HWFET) runs. The UDS runs simulate urban drives that are approximately 7.45 miles long, while the HWFET runs simulate higher speed freeway drives that are 10.2 miles long. The average speed found on the UDS was 19.6 mph, and the maximum speed was 56.7 mph. The average speed on the HWFET was 48.3 mph, and the maximum speed was 59.9 mph.

Before testing, an initial tire warm up was completed for an elapsed time of fifteen minutes. Tire warm up was performed without drawing any power from the battery pack and would typically raise the tire temperatures by about 20 to 30 degrees Celsius. The AVL Dynamometer recorded vehicle speed, acceleration, tractive force and distance traveled through its data acquisition system at one-second intervals. The plots seen in Figures 4 to 7 show the driving profiles and the location where the profile could no longer be followed.

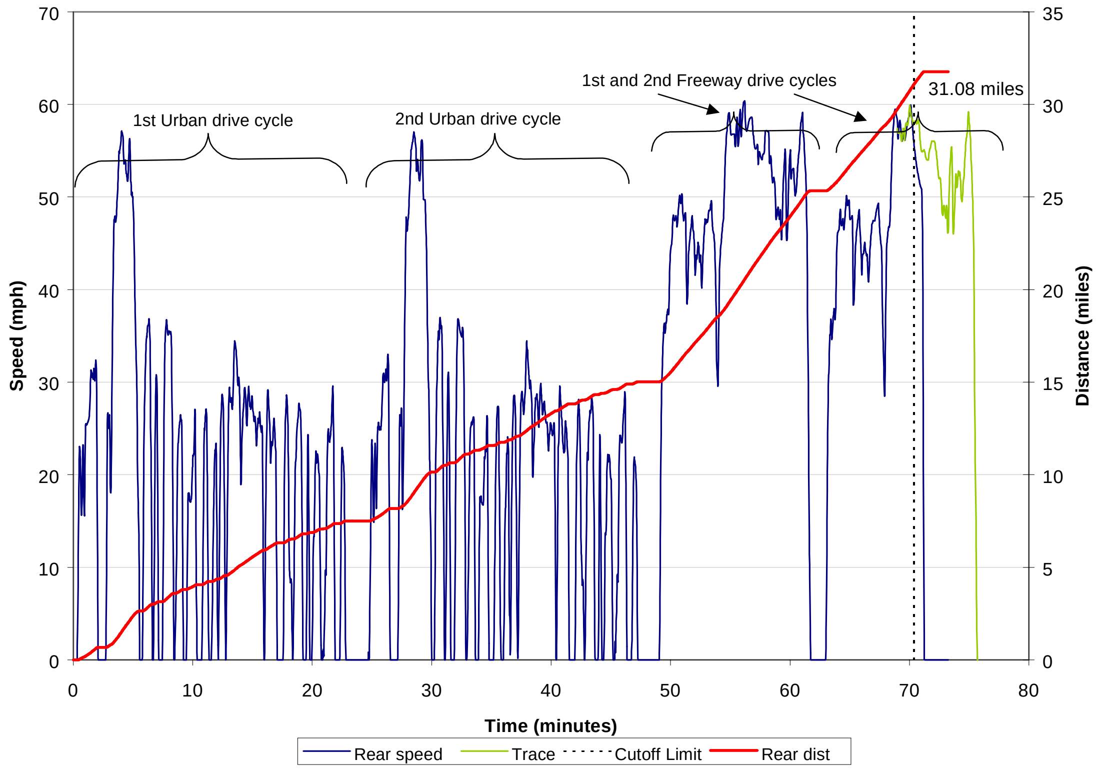

Figure 4 – Combined UDS/HWFET Drive Profile – Test 1 Vehicle 3

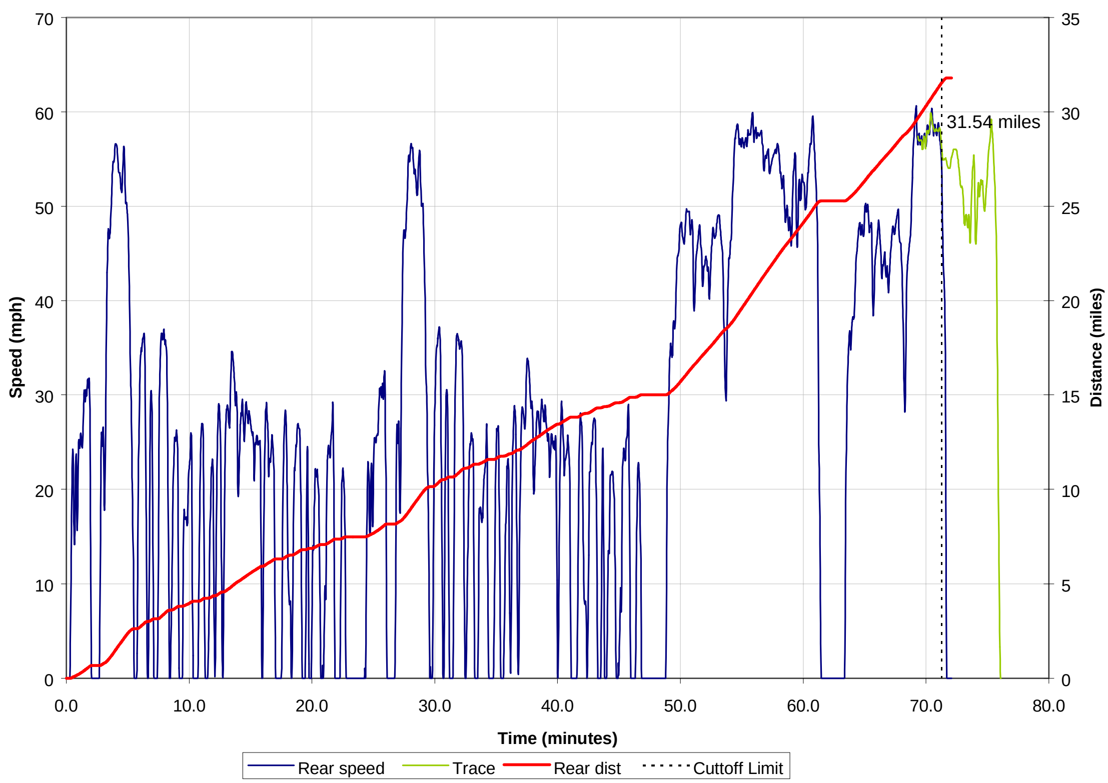

Figure 5 – Combined UDS/HWFET Drive Profile – Test 2 Vehicle 3

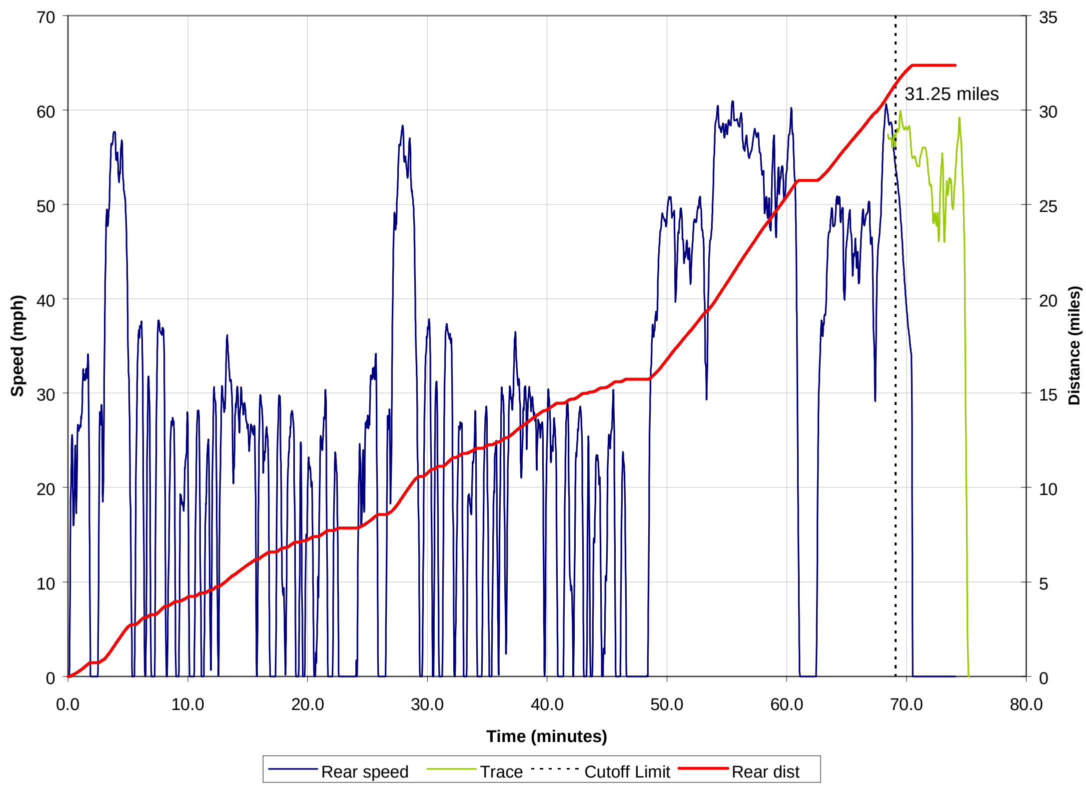

Figure 6 – Combined UDS/HWFET Drive Profile – Test 1 Vehicle 4

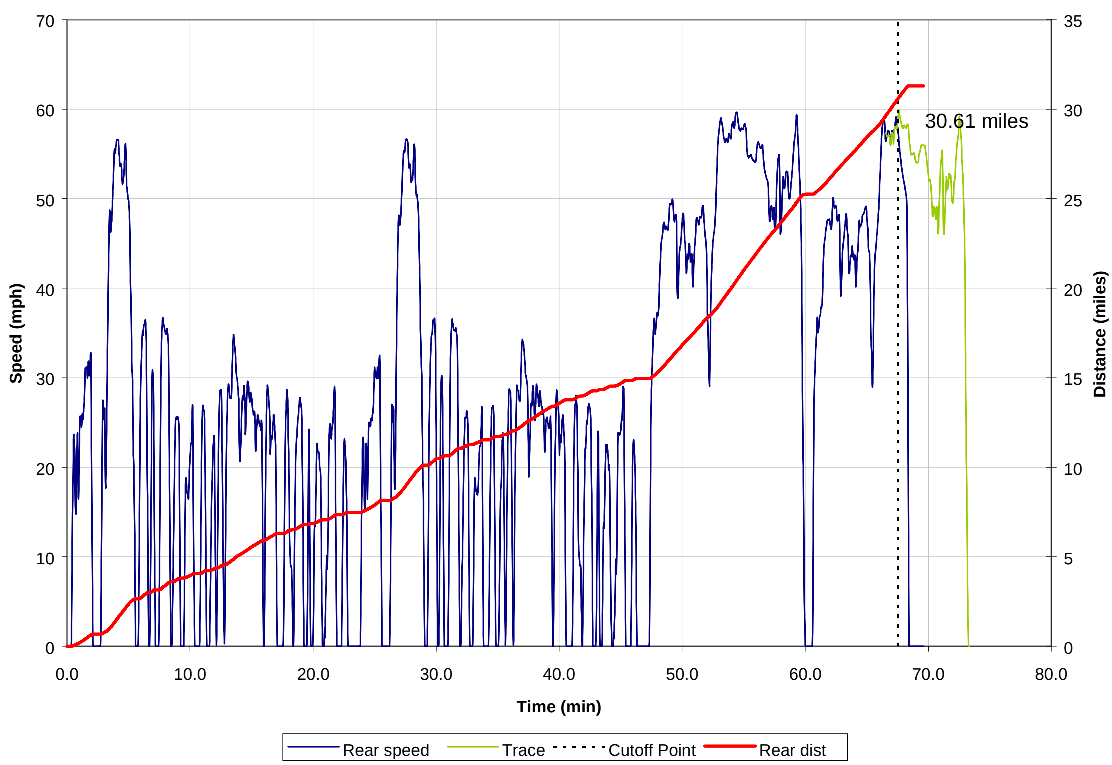

Figure 7 – Combined UDS/HWFET Drive Profile – Test 2 Vehicle 4

As can be seen from the previous figures, the postal delivery vehicles averaged 31.1 miles when tested on the combined UDS/HWFET dynamometer cycle. The end of test was determined when the vehicle could no longer follow the trace provided by the dynamometer software. Once the vehicle strayed below 2 mph from the trace, the test was stopped and the mileage was recorded. The table below shows a summary of data that was recorded by the vehicle's on-board data acquisition system as well as the mileage recorded by the dynamometer software.

Table 3 – Dynamometer Combined UDS/HWFET Range Test Results

Vehicle	Date	Start			End			DC Ah Out	DC kWh Out	Dyno Miles
		Pack Voltage	Pack Temp	Amb Temp	Pack Voltage	Pack Temp	Amb Temp			
Veh 3	11-13-00	328.0	24	23	306.7	30	25	52.7	16.2	31.1
Veh 3	11-14-00	332.9	24	22	308.3	29	25	52.4	16.2	31.5
Veh 4	11-08-00	332.6	28	23	310.6	35	25	52.1	16.2	31.3
Veh 4	11-14-00	330.8	21	22	310.2	28	25	50.8	15.7	30.6

Temperatures in Degree Celsius

It was noticed that the vehicle's odometer distance was approximately 1 mile higher than the distance determined by the dynamometer software.

Ford has also gathered dynamometer data on the postal vehicles using minimum payload.

Table 4 – Ford Dynamometer Results

EPA Test Results Performed at Minimum Payload	
City	57.0 miles
Highway	43.0 miles
Combined	52.7 miles

As can be seen from the tables, maximum payload greatly reduced the range of the vehicles to 31 miles, in comparison to the 52.7 miles for minimum payload.

Ford has confirmed that the vehicle's range is in the mid 30s when tested on the combined UDS/HWFET at maximum payload. Fords results also show that the City cycles are much more efficient than the Highway cycles, meaning that a pure city test will yield higher mileage. This is confirmed with the testing done on the Pomona Loop. The postal Vehicles average just over 40 miles, sometimes getting up to 45 miles of range on the Pomona Loop when tested at maximum payload.

Vehicle Energy Consumption on Combined UDS/HWFET Cycle

After performing the range tests, the AC and DC energy returned to the battery pack while charging was recorded for each vehicle. The DC energy from the battery was also recorded while driving the vehicles on the dynamometer cycles. Due to inefficiencies in the charging system and the battery pack, the total AC energy supplied to the battery is not available for vehicle propulsion. Three measures of energy consumption are defined below.

$$\text{System AC Energy Consumption} = \frac{\text{AC Energy to Charger for Recharge}}{\text{Distance Traveled}} \qquad \text{Equation 2}$$

(Units of AC kWh/mile)

$$\text{System DC Energy Consumption} = \frac{\text{DC Energy From Charger for Recharge}}{\text{Distance Traveled}} \qquad \text{Equation 3}$$

(Units of DC kWh/mile)

$$\text{Vehicle DC Energy Consumption} = \frac{\text{DC Energy from Battery While Driving}}{\text{Distance Traveled}} \qquad \text{Equation 4}$$

(Units of DC kWh/mile)

The table below shows the energy consumption of the vehicles in terms of AC energy required to charge the vehicles, DC energy required to charge the vehicles, and DC energy required to drive the vehicles. Equations 2-4 were used to calculate these energy consumptions. The system AC energy consumption is normally used as the electrical economy value.

Table 5 – Energy Consumption Results

	Vehicle #3	Vehicle #4
Test Date	11-13-00	11-08-00
Total Miles Driven	31.76	32.37
DC Energy Recharge (kWh)	21.23	21.45
DC Energy Driving (kWh)	16.20	16.20
AC Energy (kWh)	22.71	23.79
System AC Energy Consumption (AC kWh/mile) [Eq. 2]	0.715	0.735
System DC Energy Consumption (DC kWh/mile) [Eq. 3]	0.668	0.663
Vehicle DC Energy Consumption (DC kWh/mile) [Eq. 4]	0.510	0.500

Water Test

The water test examines the vehicle's ability to endure water hazard conditions in a short time frame. The purpose of this test is to determine the amount of leakage current from battery to chassis and from chassis to ground when the vehicle is driven through a standing water area. To reproduce the effects of splashing water, a sprinkler setup with four sprinkler heads was used for wetting the underside of the vehicle for a ten-minute duration (see photo below).

Figure 8 – Water Test Setup

Within five minutes of soaking the underside of the vehicles, they were put on charge and checked for battery leakage current from battery to chassis and from chassis to ground. To access the batteries high voltage leads, a specially designed cover was used at the high voltage junction box that connects the charger and the battery pack. SCE technicians certified to work on Ford electric vehicles performed all high voltage work.

While testing these vehicles, it was believed that they already possessed a self-leakage test that cycles every few seconds. A voltage spike was observed every four to five seconds between the battery positive or negative and the vehicle's chassis, while charging. Ford engineers, who explained that the self-test is incorporated into the vehicles charging system, confirmed the self-test theory. There are two levels of warning for leakage current. At one level the electrical hazard lamp comes on. At the second level, charge is not allowed. This self-test never allows the vehicle to operate with leakage currents over 3 milliamps. The leakage test itself produced a leakage current reading of 1.8 MIU (0.5 MIU was maximum recommended by UL) during the voltage spike between the battery and the chassis. This leads to the conclusion that all high voltage cables (orange in color) should be worked on with care. Only trained technicians, who use proper protection, such as high voltage gloves and face protection, should work on the high voltage components of these vehicles.

Under normal operation, there should not be any dangerous currents being drawn to the ground or chassis of the vehicle. The built-in leakage testing will detect any dangerous currents that fall outside of a safe range and shut down the system.

Overcharge Factor

Table 6 shows the results of energy measurements taken for successive drives and charges for vehicles 3 and 4. The drives for each vehicle were full range discharges on the Pomona USPS delivery route. The drives for the two vehicles were consistent in range, and had an average battery discharge of about 22 kWh DC. The energy return was 23.80 kWh for vehicle 3 and 23.95 for vehicle 4. Thus the energy return was 1.097 times the energy discharge for vehicle 3, and 1.081 for vehicle 4, which is about 10% energy overcharge.

Based on ampere-hour capacity, the charge return was essentially 1.0. According to Ford engineers, the postal vehicles use a patented stepped constant current charge algorithm. In normal circumstances, equalization is performed roughly once every two to six weeks, depending on vehicle usage and the condition of the battery. Ford also comments that the valve regulated lead acid (VRLA) battery used in the postal vehicle requires only a small amount of overcharge.

Table 6 – Overcharge Factor Based on kWh Usage

	DC kWh Out (Drive)	DC kWh In (Charge)	Overcharge Factor
Vehicle #3	21.69	23.80	1.097
Vehicle #4	22.17	23.95	1.081

Accelerated Reliability Test Results

Vehicle Mileage and Energy Usage

Postal vehicles 1240001 and 1240002 (also referred to as Vehicles #1 and #2) have been on an accelerated mileage regimen in which they are expected to achieve over 20,000 miles in a one-year period. During testing, all mileage, ambient temperature and energy usage is collected for each drive on log sheets. Energy is also recorded by a kilowatt-hour measuring device, which is downloaded periodically. Table 7, below, summarizes the mileage and energy usage for the testing period.

Table 7 – Vehicle Mileage and Energy Usage – As of December 6, 2000

	Vehicle #1	Vehicle #2
Start Odometer	153	143
Current Odometer	3880	3792
Total Miles Driven	3727	3649
Total ACkWh Used	2541.2	2677.0
AC kWh/mile	0.682	0.706

On-Board Data Acquisition System Data

Data has been successfully downloaded from the on-board system periodically. The on-board system is capable of recording a wide variety of information while driving and while charging. It is however recording much lower mileage numbers than those displayed by the vehicle odometers. Dynamometer tests have shown that the odometer is much more accurate than the on-board data acquisition system. The following table shows the data recorded from September 11, 2000 until December 6, 2000 for vehicles one and two. Ford will provide an updated software version that will give much more accurate readings for mileage and energy usage.

Table 8 – On-board System Data (9-11-00 to 12-6-00)

		Vehicle #1	Vehicle #2
Miles Recorded		3643.6	3684.9
Driving	Pack DC Ahrs	4740.8	4792.0
	Pack DC kWhrs	1551.8	1570.4
Charging	Pack DC Ahrs	4806.4	5106.9
	Pack DC kWhrs	1823.2	1940.7
AC kWh (Estimate)		2059.6	1955.9
AC kWh/mile (Estimate)		0.565	0.531

The plot below shows the daily mileage for vehicles one and two. Due to a higher than normal demand for testing services in September to early November, combined with an unexpected departure of two contract drivers, vehicles one and two averaged about 53 miles per day, as of December 6. Although this number is much higher than the 15 miles per day that these vehicles are expected to average in actual operation, it is lower than the Tech Center's goal of driving 80 miles per day. Even with this minor setback, the target of 20,000 miles by September 28, 2001, is expected to be achieved. The plot shows that an average mileage of over 80 miles per day is within the vehicle's capabilities in an eight-hour workday.

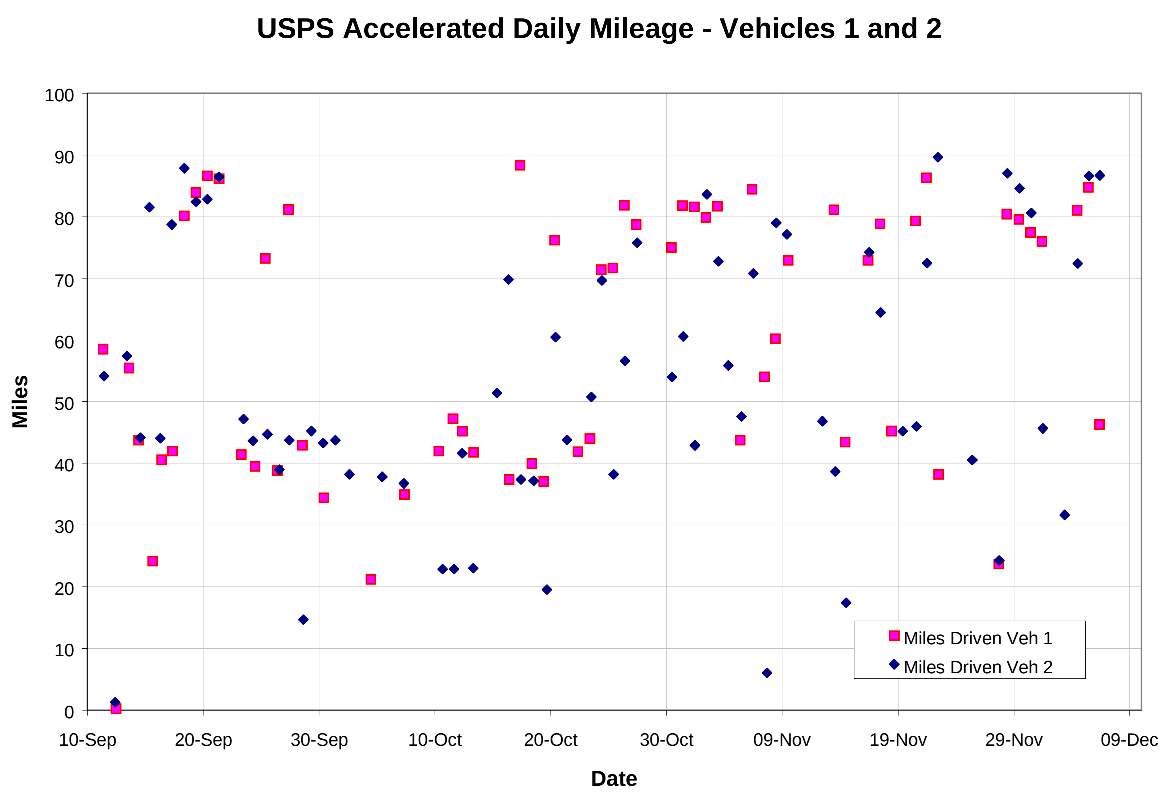

Figure 9 – Accelerated Reliability Daily Mileage

Battery information while driving and while charging is very important for determining how well the pack is performing and what kind of condition they operate in. The on-board data acquisition system is capable of recording battery temperature, battery voltage, and battery energy usage (AC and DC) as well as other relative data. Figures 10 and 11 show the energy usage of vehicles one and two respectively. Figures 12 and 13 show the maximum and minimum voltage and battery temperatures recorded while charging. These plots show that the battery temperatures vary according to ambient temperatures. Figures 14 and 15 show the maximum and minimum voltage and battery temperatures recorded while driving vehicles one and two respectively.

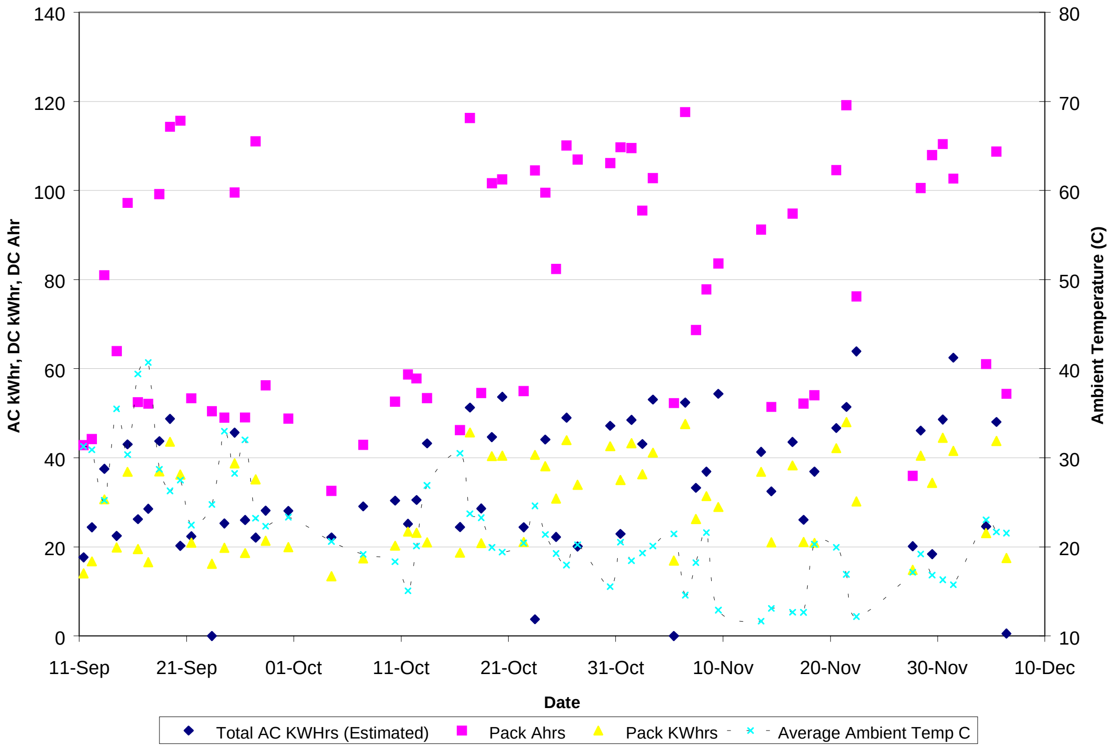

Figure 10 – Energy Usage for Vehicle 1 as of 12-6-00

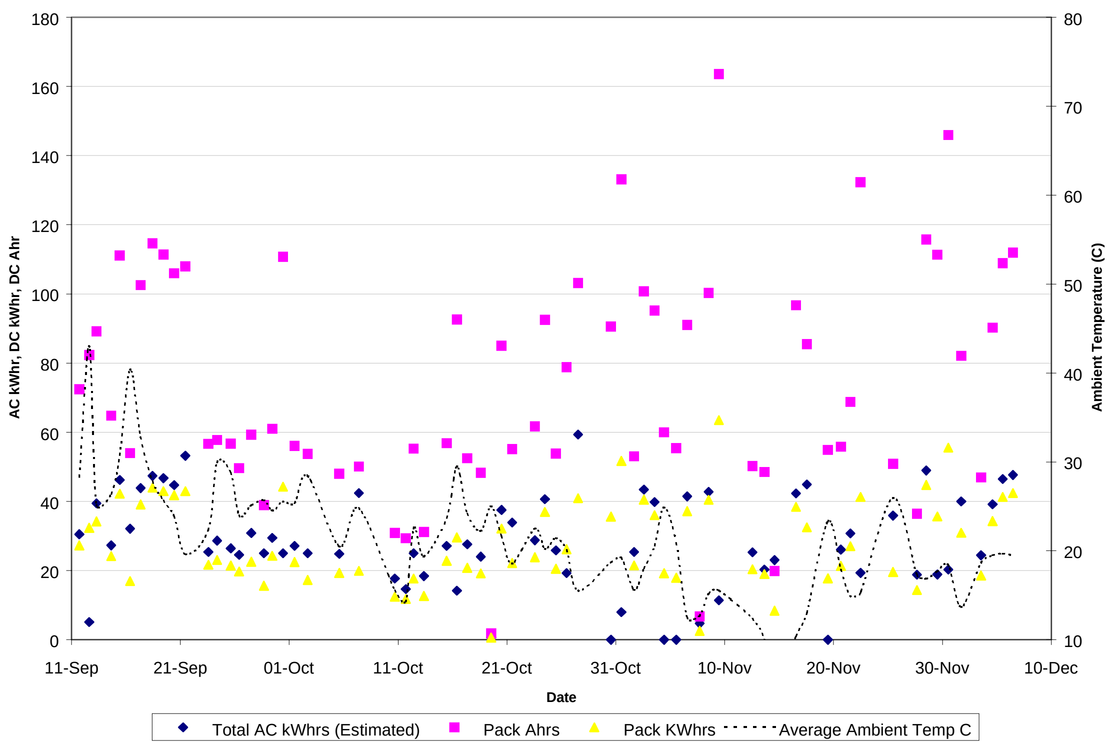

Figure 11 – Energy Usage for Vehicle 2 as of 12-6-00

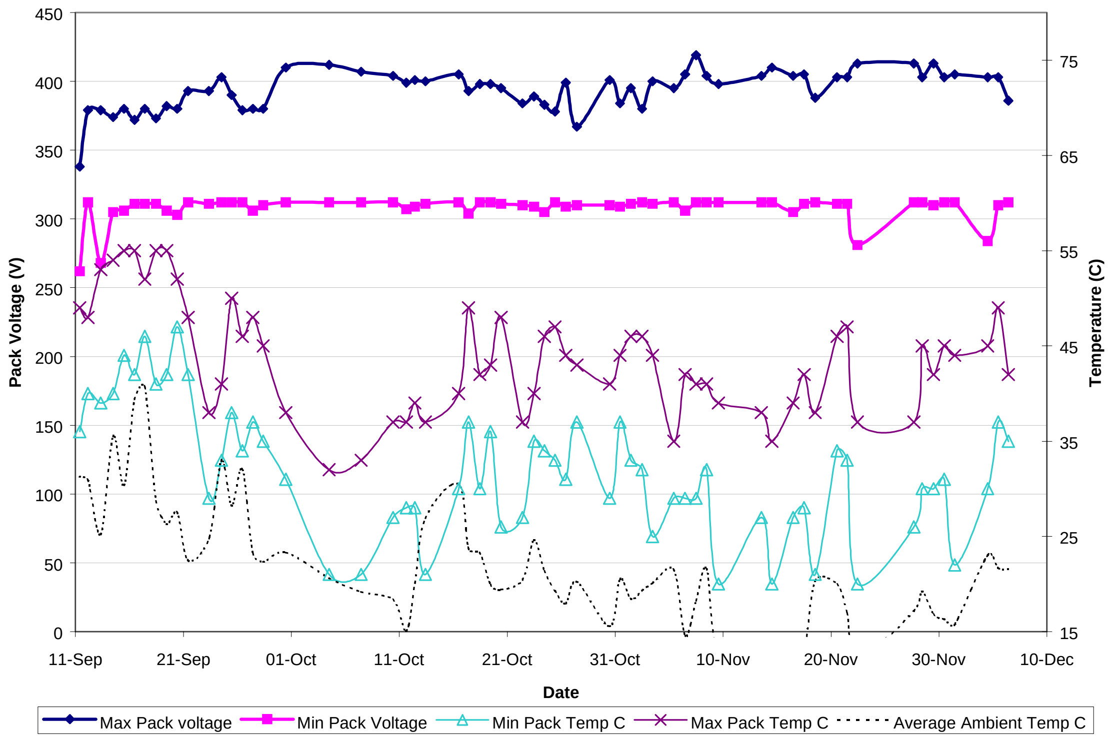

Figure 12 – Pack Voltage and Temperatures While Charging – Vehicle 1 as of 12-6-00

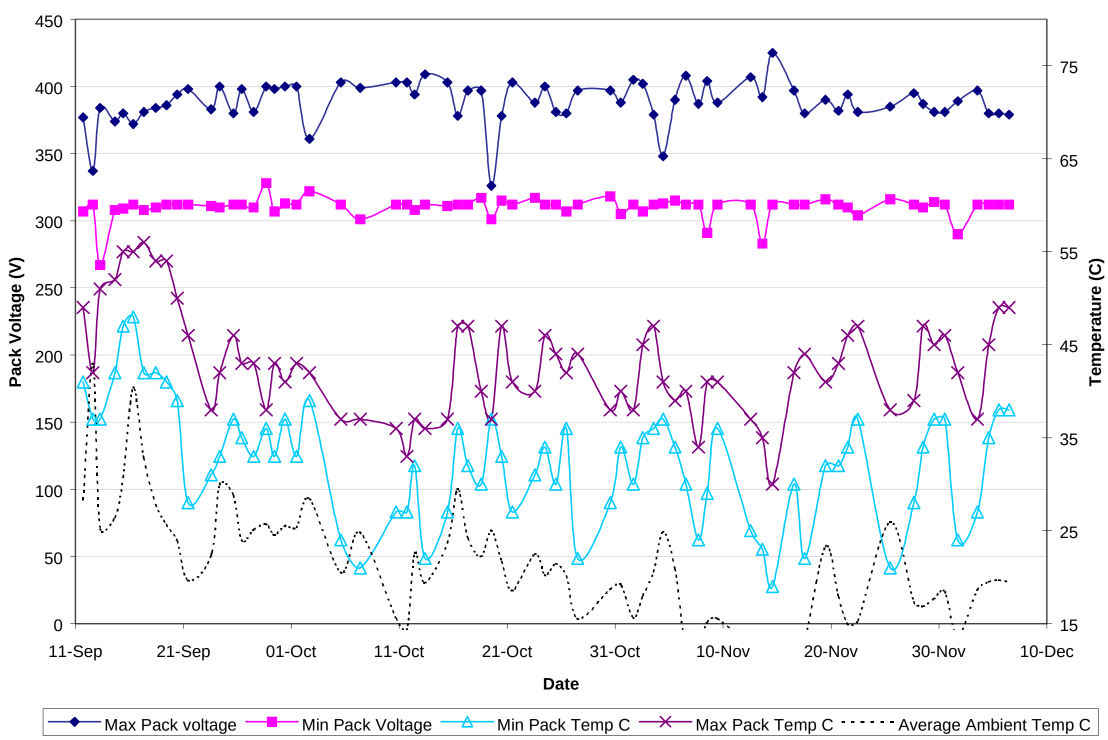

Figure 13 – Pack Voltage and Temperatures While Charging – Vehicle 2 as of 12-6-00

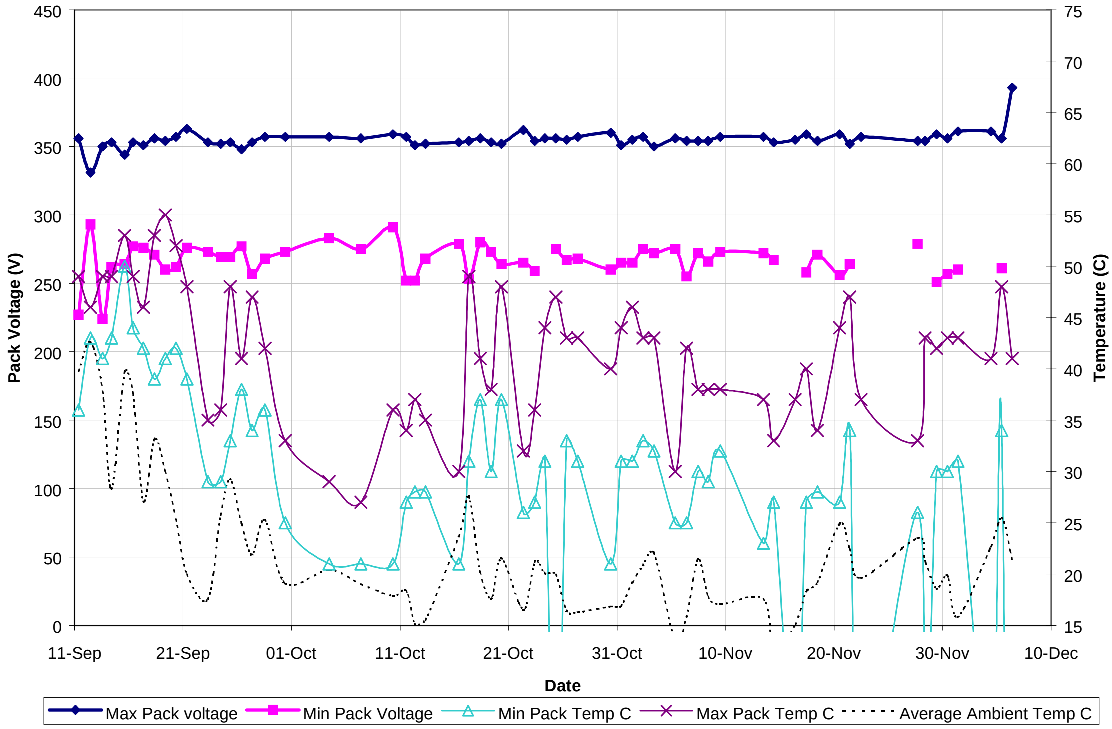

Figure 14 – Pack Voltage and Temperatures While Driving – Vehicle 1 as of 12-6-00

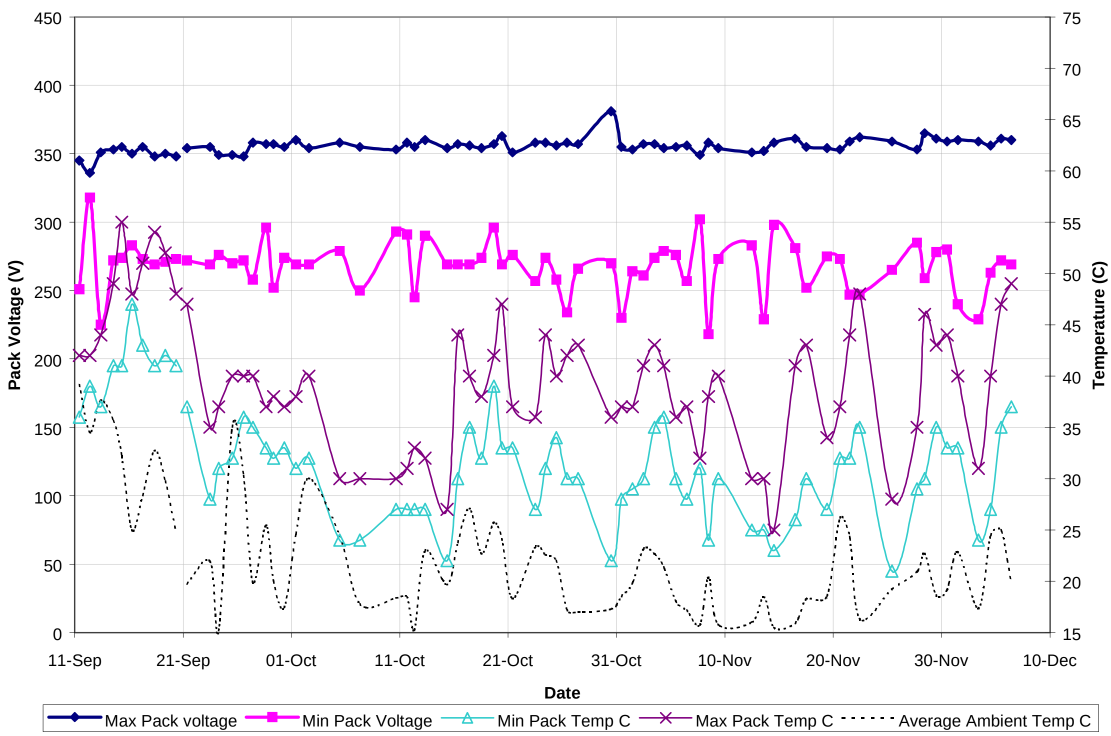

Figure 15 – Pack Voltage and Temperatures While Driving – Vehicle 2 as of 12-6-00

Vehicle Range

Range tests have been performed periodically on the accelerated reliability vehicles on the Pomona Urban Loop (See Pomona Loop Map in Appendix A). All tests were performed at maximum payload (1250lbs) with no auxiliary loads turned on (UR3).

The vehicles were driven until they reached the stop condition, which is the when the battery light begins to flash. The vehicles can be safely driven further past the stop condition for a few more miles until the Power Limit light comes on solid. When the Power Limit light begins to flash the vehicle's top speed will be reduced to 25 mph (to protect the battery pack).

Table 9, below, shows the range results for three test periods covering the months of August, October, and December. These range tests were performed on Vehicles one and two at similar time intervals. The results in the table show that the vehicles have an average range of 42 miles. The results from October and December show that the range has not reduced during that period.

For the most part, the vehicles are easily able to complete over 40 miles on the Pomona Loop. There were few occasions when the state of charge would drop to 0% on the dash gage after driving between 30-35 miles. There were also four reduced range incidents that were recorded, during which the Power Limit light turned on at approximately 28 miles.

Weekly deep discharges were instituted in order to stabilize the range performance of the vehicles. Thus far, the range has been quite stable, with the exception of some short drives due to the Power Limit light coming up early. Even after performing a deep discharge on vehicle two on 12/1/00, the vehicle experienced an early power limit warning at 27.6 miles the following day. After this incident, the vehicle has performed well into the 40s. The vehicle's range will continue to be monitored with the implemented weekly discharging, to determine if this procedure is beneficial.

Table 9 – Accelerated Reliability Vehicle Range Results

	Date Tested	Average Ambient Temp °F	Odometer Start	Odometer End	Range at Stop Condition
Vehicle #1	8-30-00	74.0	215	261	45.3
	10-12-00	70.4	1410	1452	41.9
	12-6-00	70.7	3774	3811	41.1
Vehicle #2	8-31-00	78.6	164	210	46.0
	10-12-00	70.4	1545	1584	38.5
	12-6-00	70.7	3791	3833	41.4

Vehicle Incidents During Test Period

Table 10, below, shows all the incidents that have been recorded for the accelerated reliability vehicles during the entire testing period. Since the last quarterly report, three incidents have been recorded for the month of December. Two problems that were related to reduced range, occurred on December 3rd and 10th of 2000. Both vehicles experienced a Power Limit warning light much sooner than expected. Instead of coming on after driving more than 40 miles, the light turned on after approximately 28 miles. Vehicle one was able to make it back to the Tech Center; vehicle two was towed.

The third problem, which was a minor charging problem, occurred on December 12th. The problem was associated with an electric vehicle supply equipment (EVSE) malfunction. The EVSE used for vehicle two was showing a "Service Required" light. The power to the EVSE had to be cycled before it would function normally. The anomaly that occurred with the EVSE cannot be explained at the moment, but a power disturbance is suspected.

Table 10 – Vehicle Incidents

Vehicle	Date	Description
1240002	9-7-00	Vehicles need loading straps for payload, payload shifted abruptly without loading straps on vehicle 1240002. Loading straps obtained on 9-8-00.
1240001	9-8-00	Vehicle charger noticed to be charging abnormally, approximately 10 hours to charge. Charging profile showed that charger repeatedly charged for three minutes then turned off for seven minutes until the charge was complete. Ford is aware of the situation
1240001	9-11-00	Charger not functioning. Repaired 9-13-00. New charger installed. Charger cooling fan failed.
1240002	9-11-00	When vehicle was driven to power limit mode the power steering on the vehicle became hard. High voltage fuse may be the problem. Repaired 9-12-00. High voltage fuse and power steering replaced.
1240002	10-7-00	Power Limit light on at 27.8 miles. Drive ended at 34 miles.
1240002	10-13-00	Power steering upgraded. Requested by Ford.
1240002	12-3-00	Vehicle showing power limit after only 27.4 miles, had to be towed back to EVTC. Previous day, vehicle was discharged completely. Weekend driver. Sunday drive.
1240001	12-10-00	Vehicle showing power limit lamp flashing after only 28.7 miles. Weekend Driver. Sunday drive.
1240002	12-12-00	Electric Vehicle Supply Equipment (EVSE) "Service Required" light came on. EVSE fuse box was cycled off then on. Charging now functioning normally.

Conclusion

Based on baseline test results obtained, the vehicles met all USPS requirements, except for range. Dynamometer test results averaged 31 miles. Since the vehicles are expected to average 15 miles per day in actual operation, this should not be a problem. It should be noted that urban Pomona Loop tests performed on these vehicles yielded an average of 42 miles of range.

One serious concern has been raised by reliability test results: If the vehicles are not completely discharged on a regular basis, the range performance suffers. We believe that this is a battery management issue. It will create problems in the field if not addressed prior to deployment of the vehicles. As mentioned previously, the vehicle's range will continue to be monitored with the implemented weekly discharging, to determine if this procedure is indeed beneficial.

APPENDIX A: POMONA LOOP MAP