The Optimization of an Electric Vehicle (EV) for Improved Range

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Abstract

This study focuses on possible factors affecting an electric vehicle (EV) in "real world" testing. Factors such as wind, temperature, and humidity were considered in testing range. A base model 2017 Nissan Leaf EV was modified to remove weight through altering wheel rims and car seats. Removing weight from a vehicle has been used in car racing for many years to increase vehicle speed. Through past studies focusing on new Teslas (EV), wheel rim structure has been found to increase range. Increasing the EV range through the removal of weight was thought to be possible. In addition, the Nissan Leaf was recharged while hot air was pumped underneath (for one hour from a clothes dryer) to increase battery capacity thereby adding extra kilometers to the range. There was an increase in range through recharging after the trial ended that day, it was aided by the hot air. A minimal gain in range was found after the third set of trials where weight was removed. Future research should look at pumping hot air underneath the EV (for multiple hours) while recharging during cold weather (under 0 C/32 F) to find a solution for reduced range during colder months.

Keywords: electric vehicle; Nissan Leaf; electrification; short-range; range anxiety

1. Introduction

Electric vehicles (EVs) have become more popular over the past few years because they offer cheap maintenance, a low cost to recharge, and financial incentives are often prominent during a purchase. There has been an abundance of EVs sold in the USA and Canada since 2018. Tesla leads the way (by far) in electric vehicles sold from 2018-2019. However, Chevrolet and Nissan each sold a substantial number of EVs during this time. For the years 2018-2019, the Chevrolet Bolt EC sold 34,437 units while Nissan sold 27,080 of its EV called "Leaf" (Crider, 2020).

The Nissan Leaf has been around for ten years, its début was in 2010. Battery power has increased in the Leaf over the past few years with the original 2010 model using a 24-kWh battery. More recent models including 2017 use a 30-kWh battery while 2020 includes a 40-kWh. There are two important differences between Tesla models and a Nissan Leaf—price and range. Glon and Edelstein (2020) found the price of a Tesla 3 at $39,990 (USD) including a range up to 322 miles. A Leaf is $31,600 (USD) with a range of 150 miles (Glon & Edelstein, 2020). The more affordable option is the Leaf, one of the reasons why it was chosen to be used in this study.

Expanding battery capacity and efficiency while utilized by an affordable EV continues to be a central focus in extending range. Range is a key issue when consumers are determining which EV to purchase. However, more factors than just a battery affect the final range an EV offers during "real world" journeys. Factors such as heating/air conditioning, weight, speed, terrain, wind speed, outdoor temperature and humidity can all affect a simple thirty-minute drive from point-A to point-B. It is important to look at these influencing factors and optimize those under control to positively affect the range during "real world" testing.

After turning on the EV, the range is shown in the instrumentation. The range shown often differs from the manufacturers' advertised value due to environmental factors and testing in controlled conditions. The maximum range for the consumer needs vetting through testing on city streets and highways where every day EV use occurs. In this experiment, we will investigate how altering the weight (in kg) of an EV affects range (measured in km) and how an applied heating source during recharging can help increase available kilometers before travel. Measured distances (in km) between consistent points will be recorded "in a real world" scenario to view how range has been affected by the weight and heating source.

2. Literature Review

Temperature

The outside temperature has been an influence on batteries used in electric cars since the start of mass production. Even the article title from *Automotive News (2010)*, "Nissan Leaf has 100-mile range - give or take 40%" exemplifies the questionable range advertised by Nissan because there are so many factors, including temperature, affecting it. The Nissan Leafs' chief engineer said if the 2010 model version "is stuck in stop-and-go traffic, doing 15 mph (24.3 kph) on a cold winter day with the heater on, you can count on a range of around 62 miles (100.44 kph)" (Automotive News, 2010). Temperature is a central factor in reporting any results for EVs because influence on the range is substantial.

Gustafson (2020) reported on findings from the Norwegian Automobile Federation regarding range and temperature. They tested 20 popular EVs in cold temperatures. All testing was done via the Worldwide Harmonised Light Vehicle Test Procedure (WLTP). It was found that EV range was 18.5% lower on average in the cold—outdoor temperatures ranged from 37 to 21 degrees Fahrenheit (2.7 to - 6.11 Celsius). The 2019 Nissan Leaf had a 22.3% range reduction due to the cold (Gustafson, 2020).

Iora and Tribioli (2019) completed a study focused on the "Effect of Ambient Temperature on Electric Vehicles' Energy Consumption and Range"—they used a Nissan Leaf for testing. Unfortunately, the year of the Leaf is not documented, but considering the article was created in 2018 it can be assumed the car was from that year. The study took place during winter in Winnipeg, Manitoba, Canada. It gets very cold in Winnipeg during the winter. The current study took place in Canada too. The car was driven in temperatures ranging from minus 15 C to 20 C (59 °F to 68.0 °F). Cabin heating was turned on during trials at the various temperatures to find the effect on range and power consumption. Various driving cycles were utilized during the study. The optimal range was 171 km at 20 C (68 °F), 122 km at 0 C (32 °F), and 88 km at minus 15 C (5 °F). It was discovered that using cabin heating had a substantial impact on energy consumption. Iora and Tribioli (2019) discovered a range of 150 km (93.75 miles) at 20 C (68 °F), while it reduces to about 85 km (53.13 miles) and 60 km (37.5 miles) at 0 C (32 °F) and minus 15 C (5 °F); respectively. A reduction of 28 km (17.5 miles) occurred from using the heater in cold weather. There is an impact from utilizing accessories and ambient temperature on electric cars.

Efficiencies

One important aspect of increasing EV range is taking what is currently available and making it more efficient. Beck (2019) discusses the efficiency of power converters, but many of the core issues around extending range are mentioned. A manufacturer can add more battery capacity, but the weight of the batteries then increases as does the cost. Beck (2019) says a better solution is to fix the inefficiencies already present with the EV. Power inverters convert from AC to DC or vice versa and there is some heat loss in the conversion or switching process according to Beck. The heat loss removes power available for other uses. The Pre-Switch technology Beck describes to fix the issue reduces the heat loss and makes the process more efficient. Beck (2019) determined the change in process can increase range from 5-12%. While a 5% change does not seem substantial, every inefficiency needs to be removed to increase an EVs range.

Design

Li and Zhu (2019) reviewed the styling design of electric cars. The core focus was on the aerodynamic drag of various designs and what works best with an EV. Li and Zhu (2019) discuss the wheels playing an important part in the design because they increase the drag coefficient. They found that if they covered the rear wheels then a lower drag coefficient could be attained. Overall, the styling design of the car is important because a lower drag coefficient means a more energy efficient car which is important for EVs. High energy-efficiency allows for more range in an EV.

Chappell (2017) interviewed Jean-Mark Germain, the CEO of the Dutch aluminum producer Constellium NV, about applying aluminum to the development of electric vehicles. New types of vehicles need optimal solutions, EVs are no different. Germain notes the importance of aluminum holding the EV batteries in a way to provide both cooling and heating, during winter months, to get optimal range. Constellium NV creates a hollow aluminum structure and fills it with phase change material thereby helping regulate thermal energy in the course of freezing or melting—both important with EVs using batteries. The body structures from Constellium will be used with EVs housed inside Europe to start. A report from Drucker Worldwide shows a continuing movement from steel to aluminum making cars lighter. Chappell (2017) notes by 2025 the average car will have 500 lbs. of aluminum compared to 423 in 2014. However, for EVs, the amount of aluminum should be beyond the average to help lighten the vehicles and gain range. Lightweight solutions are being sought and competition will increase from mills in the United States and Mexico.

Teslike.com (2019) is a website continually updated with Tesla EV range numbers based on the size of wheels and a few other factors. All range calculations were conducted with new Tesla models. Battery degradation had yet to occur. Models of Tesla included Model 3, X, S, and Roadster from 2010-2019. Hub caps are noted as a factor in the range. Teslike.com (2019) says the increased range was between 2.6% and 5% with the addition of Aero Hubcaps. Within the article, a generic statement involving cold winter temperatures in Minnesota says "about 30%" of decreased range can be expected (Teslike, 2019). All numbers in the study are based on calculations, not "real world" testing with factors such as wind, elevation, and temperature. No weights of the hubcaps used are revealed. The conclusion was size of tires did affect EVs including the SUV Model X with smaller sizes adding to better range.

A large gap in current knowledge about how overall weight reduction affects range in an EV exists. Minor design changes in items such as wheels and rims have been examined, but not the weight of them. "Real world" EV testing with a reduction in weight through changing rim and seat materials is non-existent —this study seeks to address this issue. Addressing this gap will culminate in learning if alternative materials used for seats and rims is beneficial to EVs for added range.

3. Methods

The QEW (Queen Elizabeth Way) highway in Ontario, Canada was chosen for this study because it is heavily used and popular. Different parts of the QEW highway have various levels of traffic over a 24-hour period based on 2016 statistics. The average daily volume of traffic (both ways) ranged from 14,600 in Fort Erie to 81,900 at the Lake Street exit in St. Catharines (Ministry of Transportation, 2016). It is a common route for people living in Toronto to take when traveling to the United States. There are approximately 4.5 million people living in the Greater Toronto Area (GTA). People from the GTA will travel to Fort Erie, Ontario, Canada which connects to I-190 South and North in Buffalo, New York, United States.

SPSS was used to analyze the data. The research uses a balanced cell design with no blank cells. All comparisons were completed with an equivalent number of trials.

Temperature and wind speed measurements were taken at Garfield Lane, St. Catharines, Thorold Stone Road in Niagara Falls, Ontario and Garrison Road, Fort Erie, Ontario. Humidity values were taken at three locations during the time of the trials: (1) St Catharines, (2) Niagara Falls, and (3) Fort Erie, using the weather.com website. The car thermometer was used for recording outdoor temperature. Air temperatures were taken multiple times each day, while traveling, to provide an average. Wind speed was measured using an anemometer held up for at least one minute (in the same location) to get an average.

There were some unique weather patterns during the "real world" trials. On May 8 there was snow and windshield wipers were used. May 11 had rain and wipers were utilized. A five-minute traffic delay occurred on

May 22. May 28 had extremely heavy rain during most of the trip to and from Fort Erie. On June 3 it rained, and windshield wipers were used. The heated steering wheel and seats were not employed any time during the trials.

A 2017 Nissan Leaf S with a 30-kWh battery was used for the research. Unlike Teslike.com (2019) research using new EVs without degradation, the test car had over 109,000 kms (67,283 miles) when testing began. The car weighs approximately 1503.18 kg (3307 lbs). The weight of the "base" tire (including wheel cover and steel rim) is 9.27 kg (20.4 lbs). The weight of the alloy wheel rim is 8.23 kg (18.1 lbs). A weight savings of 4.18 kg (9.2 lbs) was applied to weeks three and four of the trials. The change in seats removed the passenger seat and changed the driver's seat to the Alpha 1 race seat. Removing the seat eliminated 17.45 kg (38.4 lbs) of weight. Another 2.55 kg (5.6 lbs) of weight was removed through changing the seat. In total, 24.18 kg (53.2 lbs) of weight was removed for weeks 5-6 trials.

All data was gathered on weekdays from May 4, 2020 to June 12, 2020. The 2017 Nissan Leaf was driven between two points - the journey consisted of traveling from St. Catharines to Fort Erie, Ontario, Canada and back. The distance to Fort Erie was 45.9 kms (28.53 miles). Returning from Fort Erie to St. Catharines was 47 kms (29.21 miles). The speed limit (100 km/hr) was adhered to during the trials (as much as possible). LeafSpy Pro (Android application) was utilized in combination with an OBD2 connector, through a BlueTooth connection in the Nissan Leaf, to measure tire pressure, efficiency, battery temperature, and battery health (SOH). Tire pressure was kept at a constant level during the trials. The EV was charged utilizing a J1772 (Level 2) charger from ChargePoint immediately after completing the trip back from Fort Erie. A 5.49-meter tube (eighteen feet) from an electric dryer (housed in the home) was installed so hot air would blow underneath the EV for one hour while it recharged. The hot air temperature from the dryer tube was 34.8 degrees C (94.64 F) as taken by a portable thermometer. There was construction along the trial route, both traveling to and from Fort Erie. Speed was reduced to 90 km/hr in the construction zone. The air conditioning or heating was not used during the journey. All windows were up during every trial.

4. Results and Discussion

All the trials contain "real world" data as it relates to EV range. Factors such as temperature, humidity, and wind were examined as part of the study. The mid-point and final range statistics were documented. There have been some omissions of numbers based on irregular events as explained below. The State of Health (SOH) for the battery had a mean value of 82.10 during the six weeks of trials. Unlike many studies which take place in labs or under controlled conditions with models or computer simulations, "real world" trials include a used EV, like thousands of consumers purchased between 2016-2020, traveling on highways and city streets with ever changing environmental factors.

4.1 Correlations with Recharging Temperature

There were 30 trials each way with only one recharging period in-between. Table 1 represents the correlation between the recharging temperature and starting range. There is a significant correlation at the .01 level as noted. There were only two days where the range was 140 km or below, one of which was a night the EV was taken for a drive due to unforeseen circumstances. The drive at night meant recharging overnight, the only trial where this occurred. The baseline range (without the dryer) was 134 km while charging at 8 C (46.4 F). All seven days recharging at or below 8 C had range values between 140-172 kms (87.5-107.5 miles), mean was 156.86 kms (98.04 miles). Of note, the range value of 140 km (87.5 miles) was the only day not charged immediately after a trial occurred. The heating (using a dryer) of the car underside after driving for sixty minutes in an EV has a positive effect on the starting range (for the next trial).

Correlation Between Recharging Temperature and Starting Range

Table 1. Correlation of Recharging Temperature and Starting Range; ** significance at the .01 level.

		Recharging Temp	Starting Range
Recharging Temp	Pearson Correlation	1	.465**
	Sig. (2-tailed)		.010
	N	30	30
Starting Range	Pearson Correlation	.465**	1
	Sig. (2-tailed)	.010	
	N	30	30

As noted in the Literature Review, temperature was found to be correlated with range. Heat expands the capacity of the battery. The battery capacity is reflected through increased range. Table 2 shows a significant correlation at the .01 level for temperature and the ending range value. Correlation coefficients for the correlation is extremely significant with a value of .000. The strength of the association between the factors is strong with r=.829.

Correlation Between Temperature and Ending Range

Table 2. Correlation Between Temperature and Ending Range **. Correlation is significant at the 0.01 level (2-tailed).

		Mean Temp	Range End
Mean Temp	Pearson Correlation	1	.829**
	Sig. (2-tailed)		.000
	N	30	30
Range End Value	Pearson Correlation	.829**	1
	Sig. (2-tailed)	.000	
	N	30	30

Since the data was gathered in Canada in the spring, the ambient temperature naturally went up. Week 1-2 took place in May 2020, springtime in Canada. None of the following descriptive data (Table 3, 4, 5) tables had outliers or “abnormal” circumstances removed. Table 3 shows the minimum average temperature for one day was 2.67 C (36.81 F); approaching 0 C (freezing point, 32 F). It snowed on that day, May 8, in Fort Erie. Stronger winds are associated with this time of year (spring), a 9.04 kph (kilometers per hour) wind speed average during weeks 1-2 is comparably higher by 28.5% above weeks 3-4 and 24.6% for weeks 5-6.

4.2 Descriptive Statistics for all Trials

Weeks 1-2 Descriptive Statistics Including Temperature, Humidity, Wind Speed

Table 3. Descriptive Statistics from May 4 – May 15, 2020

	N	Minimum	Maximum	Mean	Std. Deviation
Mean Temp	20	2.67 C	18.67 C	9.47 C	4.75373
Mean Humidity	20	32.33%	91.67%	53.37%	18.58259
Mean Wind Speed	20	3.80 kph	17.73 kph	9.04 kph	4.64794

Weeks 3-4 Descriptive Statistics Including Temperature, Humidity, Wind Speed

Table 4. Descriptive Statistics from May 18 – May 29, 2020

	N	Minimum	Maximum	Mean	Std. Deviation
Mean Temp	20	12.33 C	24.33 C	19.50 C	4.16444
Mean Humidity	20	27.33%	89.33%	64.70%	20.35081
Mean Wind Speed	20	3.13 kph	10.67 kph	6.47 kph	2.38381

Weeks 5-6 Descriptive Statistics Including Temperature, Humidity, Wind Speed

Table 5. Descriptive Statistics from June 1 – June 12, 2020

	N	Minimum	Maximum	Mean	Std. Deviation
Mean Temp	20	13.00 C	28.67 C	19.57 C	4.68019
Mean Humidity	20	46.67%	95.00%	69.43%	13.82747
Mean Wind Speed	20	1.83 kph	12.43 kph	6.82 kph	2.79947

Humidity values across the study had two significant differences at the .10 level as shown in Table 6. Weeks 1-2 had significantly less humidity as compared to both weeks 3-4 (.051) and 5-6 (.009). However, Tables 10-12 show that humidity had a weak correlation with the range during weeks 1-2 and weeks 5-6. There was almost no relationship during weeks 3-4 between humidity and range.

Humidity Paired Samples Test

Table 6. Humidity for all six weeks – comparison of two-week trial periods

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	90% Confidence Interval of the Difference Lower	90% Confidence Interval of the Difference Upper			
Pair 1	Humidity Weeks 1-2 – Humidity 3-4	-11.33300	24.38932	5.45362	-20.76303	-1.90297	-2.078	19	.051
Pair 2	Humidity Weeks 5-6 – Humidity 3-4	4.73500	27.00244	6.03793	-5.70538	15.17538	.784	19	.443
Pair 3	Humidity Weeks 5-6 – Humidity 1-2	16.06800	24.64851	5.51157	6.53776	25.59824	2.915	19	.009

The minimum temperature of 2.67 C (Table 2) during weeks 1-2 was vastly different from weeks 3-4, 5-6 showing 12.33 C and 13.00 C; respectively (Table 2). Like humidity, temperature values across the study had two significant differences at the .10 level. Weeks 1-2 were significantly cooler compared to both weeks 3-4 (.000) and 5-6 (.000).

Temperature Paired Samples Test

Table 7. Temperature for all trials– comparison of two-week trial periods

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	90% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Temp 1-2 – Temp 3-4	-10.0310	6.53145	1.46048	-12.55636	-7.50564	-6.868	19	.000
Pair 2	Temp 5-6 – Temp 3-4	.0680	4.24312	.94879	-1.57258	1.70858	.072	19	.944
Pair 3	Temp 1-2 – Temp 5-6	-10.0990	6.52701	1.45948	-12.62264	-7.57536	-6.920	19	.000

Wind deviated from temperature and humidity in significant findings. The wind was shown to have a significant difference from weeks 1-2 to 3-4. Wind temperatures were similar in weeks 3-4 to weeks 5-6 with only a .35 kph increase. Wind from weeks 1-2 were Similarly, humidity had a slight increase of 4.73% between weeks 3-4 and 5-6.

Wind Speed Paired Samples Test

Table 8. Wind speed for all trials– a comparison of two-week trial periods

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	90% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Wind Speed Weeks 1-2 - Wind3-4	2.57000	5.20020	1.16280	.55936	4.58064	2.210	19	.040
Pair 2	Wind Speed Weeks 5-6 - Wind3-4	.34500	4.29907	.96130	-1.31722	2.00722	.359	19	.724
Pair 3	Wind Speed Weeks1-2 - Wind5-6	2.22500	5.93583	1.32729	-.07006	4.52006	1.676	19	.110

The EV range for weeks 1-2 (Table 9) shows the outlier (83) was larger than any other value during all trials, this positively skewed the data. As noted above (in Table 3), the mean wind speed was much higher during weeks 1-2 and some of those strong tail winds helped substantially increase the EVs range.

Descriptive EV Range Statistics

Table 9. EV range statistics to Fort Erie, ON and back

	N	Minimum	Maximum	Mean	Std. Deviation
Weeks 1-2	20	30	83	57.40	11.677
Weeks 3-4	20	33	78	55.95	13.896
Weeks 5-6	20	29	76	54.35	12.646

Table 10 includes the results of journeying to and from Fort Erie, Ontario under three testing circumstances – no weight change (weeks 1-2), changing the wheel rims (weeks 3-4), and altering seats plus rims (weeks 5-6). There was a mean range of 56.05 kms for weeks 1-2 including removing a higher than "normal" range value due to weather. There was a strong tail wind on May 15 which explains a 19% increase in range over the average. Weeks 3-4 (in Table 8) excluded values (78,33) because of traffic and weather. On May 20, high head winds and heavy traffic occurred, only 33 kms of range remained due to high battery usage. May 28 had heavy rain and traffic. During rain, the wipers were used causing power to be expended. Weeks 3-4 provided a mean range of 56.00. Weeks 5-6 had two outliers removed (29,31) due to unusual weather and a cold recharge. June 10 saw high tail winds (10.3 kph; like May 15) with only 31 kms of power used. On June 11, the car was recharged overnight and did not have the typical (one hour of travel) charging after high usage. A mean range value for weeks 5-6 showed 57.06 kms. The increase in range is 1.02% after removing 24.18 kg (53.2 lbs).

Table 10. Range statistics to Fort Erie, ON and back (two trials per day) excluding outliers' data

Range Statistics Weeks 1-2		Range Statistics Weeks 3-4		Range Statistics Weeks 5-6	
N Valid	19	N Valid	18	N Valid	18
Mean Range (Kms)	56.05	Mean Range (Kms)	56.00	Mean Range (Kms)	57.06
Median	58.00	Median	52.00	Median	56.00
Std. Deviation	10.277	Std. Deviation	12.499	Std. Deviation	10.056
Minimum	30	Minimum	38	Minimum	43
Maximum	68	Maximum	75	Maximum	76

Pearson correlation scores (in Table 11) indicate a low strength of association for EV range across all three factors (Temperature, Humidity, Wind Speed). The correlation coefficients for all three do not differ significantly, no values approach .10. It was expected that temperature would be correlated with EV range in all trials. Two explanations are possible for the lack of a strong correlation: (1) There were not enough trials used, and (2) The distance was not great enough to have an impact.

Week 1-2 Correlations for Range

Table 11. Correlation scores for 3 Factors (Temperature, Humidity, Wind Speed) with Range in Weeks 1-2

		Range	Mean Temp	Mean Humidity	Mean Wind Speed
Range	Pearson Correlation	1	-.085	.254	-.092
	Sig. (2-tailed)		.722	.280	.699
	N	20	20	20	20
Temperature	Pearson Correlation	-.085	1	-.077	.308
	Sig. (2-tailed)	.722		.748	.186
	N	20	20	20	20
Humidity	Pearson Correlation	.254	-.077	1	.132
	Sig. (2-tailed)	.280	.748		.578
	N	20	20	20	20
Wind Speed	Pearson Correlation	-.092	.308	.132	1
	Sig. (2-tailed)	.699	.186	.578	
	N	20	20	20	20

Like weeks 1-2, weeks 3-4 indicate there are very low strengths of correlation with all three factors (Temperature, Humidity, Wind Speed) and EV Range. Correlation coefficients for the three factors were extremely insignificant with none approaching the .10 level (Table 12).

Week 3-4 Correlations for Range

Table 12. Correlation scores for 3 Factors (Temperature, Humidity, Wind Speed) with Range in Weeks 3-4

		Range	Mean Temp	Mean Humidity	Mean Wind Speed
Range	Pearson Correlation	1	-.027	.002	-.018
	Sig. (2-tailed)		.909	.993	.939
	N	20	20	20	20
Temperature	Pearson Correlation	-.027	1	-.002	-.273
	Sig. (2-tailed)	.909		.994	.245
	N	20	20	20	20
Humidity	Pearson Correlation	.002	-.002	1	-.090
	Sig. (2-tailed)	.993	.994		.707
	N	20	20	20	20
Wind Speed	Pearson Correlation	-.018	-.273	-.090	1
	Sig. (2-tailed)	.939	.245	.707	
	N	20	20	20	20

Weeks 5-6 had slightly different results than previous weeks. Correlations are weak for all three factors: -.211, .200, -.200 (Table 13). The weight was lessened for the vehicle and strong headwinds from Lake Erie would explain the negative correlation value from wind.

Week 5-6 Correlations for Range

Table 13. Correlation scores for 3 Factors (Temperature, Humidity, Wind Speed) with Range in Weeks 5-6

		Range	Mean Temp	Mean Humidity	Mean Wind Speed
Range	Pearson Correlation	1	-.211	.200	-.200
	Sig. (2-tailed)		.373	.398	.399
	N	20	20	20	20
Temperature	Pearson Correlation	-.211	1	-.262	.368
	Sig. (2-tailed)	.373		.264	.111
	N	20	20	20	20
Humidity	Pearson Correlation	.200	-.262	1	-.017
	Sig. (2-tailed)	.398	.264		.943
	N	20	20	20	20
Wind Speed	Pearson Correlation	-.200	.368	-.017	1
	Sig. (2-tailed)	.399	.111	.943	
	N	20	20	20	20

Discussion

As consumers, we need to have "real world" examples because EVs are not being driven in lab-controlled environments. Many EVs are being driven for multiple years, so studying new models with 100% SOH is not applicable to most drivers. These results can apply to many models of EV with lower battery capacity such as the Ford Focus Electric, Nissan Leaf, BMW i3 and Hyundai Ioniq.

Moving to a lighter alloy spoke-style rim compared to steel wheel rims does not make a significant difference over 92.9 kms (58.06 miles). There was not enough weight differential between the steel rims and the ones tested. The spoke-design for the alloy rim did not significantly benefit the EV. More styles and lighter weight wheel rims should be examined in future "real world" trials.

It appears a heating source underneath the EV is an effective tool for increasing the range (kilometers/miles available) during spring months in Canada and the northern United States (New York, Ohio, Michigan, etc.) Like Iora & Tribioli (2019), this study found similar starting range values with 16 C plus dryer output equating to 174 km (108.75 miles) of range compared to 171 km (106.88 miles) at 20 C for their EV. The baseline starting range of 134 km (83.75 miles) at a recharging temperature of 8 C is lower than all three range values when heat from the dryer is applied. At 8 C, starting range values using the dryer heat were 140 (87.5), 152 (95), and 172 kms (107.5 miles). The 172 km (107.5 mile) range value can be explained by an increasing ambient temperature during the day while charging.

There were time constraints on the testing. For practicality, only ten trials (to and from) per week were conducted. Twenty range values were generated based on the ten trials. 2787 kms (1741.88 miles) in "real world" conditions were completed for this study.

There were many problems that occurred during the process of trying to get readings and values. The purchase of the wheel rims via Amazon was problematic because the advertised weight was incorrect and there was not enough time for a return and repurchase. A 1.05 kg (2.3 lbs.) “actual” difference in the weight of the steel wheel rims versus an advertised difference of 4.27 kg (9.4 lbs.) would have a possibly created more significant results.

There are two important findings within this study (1) A heating source applied to the battery area while recharging will help add range, and (2) Increased range is possible with weight reduction in an EV. The increased range of 1.02% after removing 24.18 kg (53.2 lbs) was lower than expected. Removing 24.18 kg (53.2 lbs) from a car weighing approximately 1503.18 kg (3307 lbs) will only add approximately 1.73 kms (1.08 miles). The 24.18 kg (53.2 lbs) removed represents 1.6% of the overall car weight. Removal of 145.08 kg (319.2 lbs.) seems to be the least amount of weight reduction for double-digit gains in range. Many of the lower capacity battery EVs would benefit from using lighter construction materials to add this double-digit gain. Manufacturers such as Nissan and Ford typically use similar seats and wheel rims included in their standard combustion vehicle engine offerings. EVs need redeveloping from the ground up to maximize their potential range.

5. Conclusion

EVs are now a viable option for traveling short and long distances in North America. Battery capacity is improving on a continual basis. However, the construction of the actual EV needs to be rethought to gain additional range efficiencies. A five-kilometer addition in range, with minimal design changes, can mean the difference from making it to a recharging area or not. Practical heating options for keeping batteries warm during recharging in the fall, spring, and winter need to be researched.

Since EVs are a relatively new area of study, there are many opportunities for future research in the “real world.” More trials need to be conducted over a longer time to get improved results. Future research should focus on adding a heating source under the car while recharging for all 4.5 hours (using a Level 2 charger) to extend range in the winter. Research using used EVs with altered wheel rims, including an “aero style”, like some Teslas use, should be tried and tested to see if added range is gained. Different materials that remove weight from an EV need to be tested so range can be extended without additional battery upgrades. EVs are different than ICE vehicles and their design materials need to be updated.

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