ELECTRIC VEHICLE PERFORMANCE AND BATTERY LIFE OPTIMIZATION - A DESIGN OF EXPERIMENTS APPROACH

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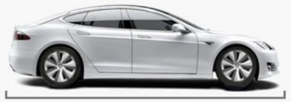
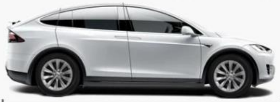
Background Description

- Tesla vehicles can travel some of the longest driving ranges of any other production electric vehicle on the market. It is natural for estimated range to change, particularly over time with driving habits and environmental factors.
- Optimizing the battery life and performance of electric vehicles simultaneously remains a significant challenge.
- On research study, it has been identified the external factors that might affect battery performance and cycle life as temperature, charging rate, driving speed, battery condition, and road type.
- Batteries once manufactured and shipped, engineering team does not have any control over these factors. But these factors will probably affect the battery life.
- Factors can be controlled in a simulation lab for the purpose of the test and results will be monitored through Tesla's 'The Energy app'.

Tesla Model S Long Range	Tesla Model 3 Long Range		Tesla Model X Long Range	Tesla Model Y Long Range
				
196" L x 77" W x 57" H	185" L x 73" W x 57" H		198" L x 79" W x 66" H	187" L x 76" W x 64" H
3.7 s	4.4 s	0-60 MPH	4.4 s	4.8 s
155 mph	145 mph	Top Speed	155 mph	135 mph
391 mi	322 mi	Range	351 mi	316 mi
100 kWh	74 kWh	Battery	100 kWh	74 kWh
517 hp	346 hp	Power	417 hp	346 hp
60 cu ft	44 cu ft	Cargo Space	88 cu ft	68 cu ft

Hypothesis

The hypothesis of the experiment is that by optimizing the factors, we can improve vehicle performance and cycle life. It is essential to recognize that these factors are interrelated and can interact with each other in complex ways.

The experiment's outcomes will help the engineering team to design a robust battery to withstand variation from external factors. The results obtained from this experiment will be communicated to customers through the Energy app, providing valuable insights into the impact of various driving behaviors and environmental factors on the performance of their vehicles.

From the experiment, we would like to answer the following questions:

- How do external factors impact the battery life and vehicle performance (range) of electric vehicles?
- What are the best conditions to maximize vehicle performance and battery life simultaneously?

Experimental Factors and Treatment Design

Factor	Low	High
Operating Temperature	-4°F	122°F
Storage Temperature	32°F	86°F
Driving speed	30 MPH	70 MPH
Charger Type	Supercharger	Low Voltage Charger
Battery Type	Lithium Ion	Nickel Metal Hydride
Battery Condition	Used	New
Road Type	City Driving	Highway

Experiment design
- Randomized complete block design (RCBD).

Treatment design
- 2^(7-2) factorial design.

Blocking Factors:
Block 1 – Battery Age
Block 2 – Road Type

StdOrder	RunOrder	CenterPt	Blocks	Operating Temperatures	Storage Temperatures	Speed	Charger Type	Battery Type	Battery condition	Road Type
1	1	1	1	-4	32	30	Low Voltage Charger	Lithium Ion	New	Highway
2	2	1	1	122	32	30	Low Voltage Charger	Lithium Ion	Used	City
3	3	1	1	-4	86	30	Low Voltage Charger	Lithium Ion	Used	City
4	4	1	1	122	86	30	Low Voltage Charger	Lithium Ion	New	Highway
5	5	1	1	-4	32	70	Supercharger	Lithium Ion	New	City
6	6	1	1	122	32	70	Supercharger	Lithium Ion	Used	Highway
7	7	1	1	-4	86	70	Supercharger	Lithium Ion	Used	Highway
8	8	1	1	122	86	70	Supercharger	Lithium Ion	New	City
9	9	1	1	-4	32	70	Low Voltage Charger	Nickel Metal Hydride	Used	City
10	10	1	1	122	32	70	Low Voltage Charger	Nickel Metal Hydride	New	Highway
11	11	1	1	-4	86	70	Low Voltage Charger	Nickel Metal Hydride	New	Highway
12	12	1	1	122	86	70	Low Voltage Charger	Nickel Metal Hydride	Used	City
13	13	1	1	-4	32	30	Supercharger	Nickel Metal Hydride	Used	Highway
14	14	1	1	122	32	30	Supercharger	Nickel Metal Hydride	New	City
15	15	1	1	-4	86	30	Supercharger	Nickel Metal Hydride	New	City
16	16	1	1	122	86	30	Supercharger	Nickel Metal Hydride	Used	Highway
17	17	1	2	-4	32	70	Low Voltage Charger	Lithium Ion	Used	Highway
18	18	1	2	122	32	70	Low Voltage Charger	Lithium Ion	New	City
19	19	1	2	-4	86	70	Low Voltage Charger	Lithium Ion	New	City
20	20	1	2	122	86	70	Low Voltage Charger	Lithium Ion	Used	Highway
21	21	1	2	-4	32	30	Supercharger	Lithium Ion	Used	City
22	22	1	2	122	32	30	Supercharger	Lithium Ion	New	Highway
23	23	1	2	-4	86	30	Supercharger	Lithium Ion	New	Highway
24	24	1	2	122	86	30	Supercharger	Lithium Ion	Used	City
25	25	1	2	-4	32	30	Low Voltage Charger	Nickel Metal Hydride	New	City
26	26	1	2	122	32	30	Low Voltage Charger	Nickel Metal Hydride	Used	Highway
27	27	1	2	-4	86	30	Low Voltage Charger	Nickel Metal Hydride	Used	Highway
28	28	1	2	122	86	30	Low Voltage Charger	Nickel Metal Hydride	New	City
29	29	1	2	-4	32	70	Supercharger	Nickel Metal Hydride	New	Highway
30	30	1	2	122	32	70	Supercharger	Nickel Metal Hydride	Used	City
31	31	1	2	-4	86	70	Supercharger	Nickel Metal Hydride	Used	City
32	32	1	2	122	86	70	Supercharger	Nickel Metal Hydride	New	Highway

Experimental Design Procedure

The experimental design procedure for the treatment design provided would involve selecting a sample of electric vehicles and randomly assigning them to the 32 treatment combinations listed in the design. The experiment will be executed in a test lab in a controlled environment using battery testing equipment and simulation. The experiment would involve measuring the battery capacity of each vehicle under the specific combination of factor levels assigned to it. The vehicle is fully charged and parked overnight. The following day, the vehicle is driven on a dynamometer which is a treadmill for cars. The dynamometer is simulated for the road types such as city and highway routes.

- The first step in the experimental design procedure is selecting the appropriate treatment design. In this case, a quarter fractional factorial design is used with two levels for each factor, and 2 blocks resulting in 32 experimental conditions.
- Battery age and road type are included as blocking factors, which can help to reduce the variability of the response due to extraneous factors that are not of interest in the experiment.
- The second step is the randomization of treatments. The treatments, which in this case are the different experimental conditions, will be randomly assigned to the experimental units, which in this case are electric vehicles. Randomization ensures that any potential bias is eliminated, and the results are representative of the population.
- The third step is sample size determination. A sample size calculation will be performed to determine the minimum number of observations needed to ensure statistical power. This calculation considers the desired level of significance, the expected effect size, and the variability of the response variables.
- Finally, the fourth step is data collection. Multiple observations will be collected for each experimental condition to account for measurement variability. This will ensure that the results are reliable and accurate. The observations will be collected using battery testing equipment, which will measure the response variables – range and battery life.

Response Variables

The response variables that are being studied in this experiment are:

Range: Range is defined as the distance an electric vehicle can travel on a single charge. Range is an important performance indicator as it determines the usability of the electric vehicle.

Battery Life: Battery life is measured as an estimate of remaining battery life as a percentage or number of miles/kilometers remaining on the dashboard or in the app.

The remaining capacity of the battery after each run can be determined form the **Tesla Energy App.**

The number of observations that need to be collected are 32. This is because we have taken a quarter fraction factorial experiment (2^7-2). This number is set because conducting a full factorial experiment with replications will require collecting the response values greater than 128 observations which can lead to excessive use of resources and time for the company.

Therefore, by conducting the mentioned experiment, the results obtained will be able to justify the hypothesis and answer the questions asked in the beginning and also, it does not lead to any kind of wastage for the company.

Analysis of the Response Variables

The analysis plan begins by outlining the statistical methods that will be used to estimate the effects of the different factors on the response variables. Factorial regression analysis will be used to model the relationship between the response variables and the different experimental factors, and ANOVA will be used to determine significant effects and interactions.

- **Factorial regression** - In the context of this experiment, factorial regression analysis will be used to estimate the effects of operating temperature, storage temperature, charging rate, driving speed, battery type, battery condition, and road type on battery life, and range. The regression models will include the main effects for each of these factors, as well as interaction effects between pairs of factors.
- **ANOVA** - Once the regression models have been developed, ANOVA will be used to determine which of the main effects and interaction effects are statistically significant.
- **Residual Analysis** - Diagnostic plots and residual analysis will be used to check the residuals of the statistical model to ensure that they are normally distributed, have a constant variance, and are independent. If any of these assumptions are not valid, remedial actions will be taken, such as transforming variables, removing outliers, or including additional variables.
- The response optimizer will be used to simultaneously find the optimum settings to achieve the maximum values for the range and the battery life.
- Based on the factors in the experiment and the number of levels for each factor, a Simplex Lattice Design can also be used for this experiment as the sum of levels of each of the factors will be equal to 100 percent.

Assessing the Model Assumptions

Before the model can be used to make predictions, it is important to verify that the assumptions of the statistical model are valid. The following assumptions are needed to be verified for validating the model.

Normality - The first step in validating model assumptions is to check for normality. Normality is an assumption that the errors or residuals in a statistical model are normally distributed. In a normal probability plot, the residuals are plotted against a theoretical normal distribution. If the residuals follow a straight line, then the normality assumption is met.

Homoscedasticity - The second step in validating model assumptions is to check for constant variance. Constant variance is an assumption that the variance of the errors or residuals is constant across all levels of the predictor variables (Factors). One way to check for constant variance is to plot the residuals against the fitted values. If the residuals are randomly scattered around zero and there is no pattern, then the constant variance assumption is met. However, if the residuals exhibit a pattern, such as a cone shape or a funnel shape, then the constant variance assumption is violated.

Independence - The third step in validating model assumptions is to check for independence of errors. Independence of errors is an assumption that the errors or residuals are not correlated with each other. One way to check for independence of errors is to plot the residuals against time order. If the residuals are randomly scattered around zero and there is no pattern, then the independence of errors assumption is met. However, if the residuals exhibit a pattern, such as a trend or a cycle, then the independence of errors assumption is violated.

Evaluation of Results

- To evaluate the results of the experiment, the estimated effects of each factor on the response variables will be examined. This will include both main effects and interaction effects. Any factors that have a significant effect on the response variables will be identified, and the direction and magnitude of the effect will be determined. This will provide insight into the key factors that influence the performance and battery life of the electric vehicle.
- Additionally, a statistical hypothesis test will be performed to determine if the differences in means are statistically significant. A confidence interval will be calculated to determine the range of values within which the true mean response is likely to lie. If the confidence interval does not include zero, then the difference is considered statistically significant at the chosen level of significance.
- **Residual Analysis:** We analyze the residuals of our regression model. Plotting the residuals against the predicted values or the independent variables will help to identify any patterns or trends that may indicate issues with model performance. Ideally, if model is performing as expected, the residuals are randomly distributed around zero with constant variance, indicating that the model is capturing the underlying patterns in the data.
- **Model Fit Measures:** Assess the goodness of fit of the model using appropriate measures such as R-squared, adjusted R-squared, and root mean squared error (RMSE). These measures provide information about how well the model explains the variation in the data and how accurately it predicts the dependent variable.

Potential Outcomes

Experimental Outcomes:

Outcome 1:Confirmation of Hypothesis

Action Plan:

Identification of Significant Factors

Optimization of Battery Design

Optimization of Driving Conditions

Development of Predictive Models

Outcome 2: Identification of Insignificant Factors

Action Plan:

Simplification of Design and Use

Outcome 3: Identification of Negative Factors

Action Plan:

Mitigation of Negative Factors

Outcome 4: Identification of Trade-Offs

Action Plan:

Optimization of Trade-Offs using the response optimizer

Outcome 5: Unexplained Variability in the model

Action Plan:

Further Investigation of the Factors

Outcomes from the Energy App:

Based on insights from the experiment

- Monitor the amount of energy the vehicle uses while driving and parked.
- See how much energy is consumed by different vehicle components, driving behaviors and environmental conditions.
- Compare the actual energy used to the trip projection and the battery indicator.
- Receive personalized suggestions for using energy more efficiently based on your driving patterns.