# Prescriptive Analysis for Fuel Efficiency Optimization

In our quest to enhance the performance and environmental sustainability of premium gas vehicles, this analysis focuses on key vehicle attributes that influence fuel consumption. By strategically adjusting cylinders, horsepower, displacement, and weight, we aim to significantly improve fuel efficiency. This prescriptive analysis sets out to identify the optimal configurations of these variables to balance robust performance with superior fuel economy, aligning with industry standards and consumer expectations.

**Decision Variables:**

- **Cylinders**: Typically, fewer cylinders in an engine can lead to better fuel efficiency. Adjusting the number of cylinders helps balance performance demands with fuel economy, especially critical in premium vehicles where expectations for both are high.
- **Horsepower**: This is a major determinant of a vehicle's acceleration and overall power. Higher horsepower usually means higher fuel consumption. Optimizing horsepower involves calibrating the power output to maintain excellent performance without excessive fuel use.
- **Displacement**: This refers to the engine's size in terms of cylinder volume. Smaller displacement often leads to better fuel efficiency because smaller engines generally use less fuel to maintain the same level of performance.
- **Weight**: The vehicle's weight significantly affects its fuel efficiency. Reducing weight can improve mileage as less energy is required to move a lighter vehicle.
- **Acceleration**: This variable is critical as higher acceleration often leads to increased fuel consumption. Our goal is to finely tune acceleration to ensure it meets performance needs while minimizing fuel use, enhancing efficiency particularly in stop-and-go traffic.

**Objective Function:**

- **Maximizing Fuel Efficiency**: The optimization function is designed to maximize the vehicle's fuel efficiency by finely tuning each decision variable. The function will adjust the cylinders, horsepower, displacement, weight and acceleration within practical design limits to find the optimal balance that maximizes efficiency without sacrificing performance.

**Strategy and Implementation:**

The approach will involve detailed modeling and simulations to determine how adjustments to these variables affect fuel efficiency under various conditions. This analytical process will guide the engineering adjustments necessary to optimize each variable effectively.

By focusing on these critical aspects of vehicle design, we can significantly enhance the fuel efficiency of vehicles using premium gas. This will not only improve cost-effectiveness for users but also contribute to broader environmental goals by reducing overall fuel consumption. The outcome will be a line of vehicles that are both high-performing and fuel-efficient, meeting the modern consumer's demands and regulatory standards.

| Optimize fuel efficiency for vehicles | | | | | | |
|---|---|---|---|---|---|---|
| Premium Gas | | | | | | |
| | Intercept | Cylinders | Displacement | Horse Power | Weight | Acceleration |
| Linear Model Data | 45.7567705 | -0.3932854 | 0.0001 | -0.0428125 | -0.0052772 | -0.3325462 |
| Upper Fence | | 0.8001 | 1.005 | 0.9388 | 0.9943 | 0.8767 |
| | | <= | <= | | <= | <= |
| Optimal | -0.5 | 0.8001 | -0.9947 | 0.9388 | 0.9943 | 0.8767 |
| | | >= | >= | | >= | >= |
| Lower Fencer | | -1.1998 | -0.9947 | -1.0611 | -1.0056 | -1.1232 |
| Optimal Solution | -23.53013512 | | | | | |

## Optimization of Fuel Efficiency for Vehicles Using Premium Gas

The table you're working with provides a structured overview of a linear regression analysis complemented by optimization constraints aimed at maximizing fuel efficiency in vehicles. Here's a breakdown of each component from your table:

### Linear Model Data

- **Intercept (45.75767705)**: This figure represents the base level of fuel efficiency when all other variables are held constant at zero. It serves as a starting point in the model, indicating the fuel efficiency of a hypothetical base model vehicle.

**Variable Coefficients**:

- **Cylinders (-0.3932854)**: This coefficient suggests that an increase in the number of cylinders is associated with a decrease in fuel efficiency. Each additional cylinder reduces fuel efficiency by approximately 0.393 units.
- **Displacement (0.0001)**: Indicates a marginal impact on fuel efficiency from engine displacement, suggesting that larger engines have a very slight increase in efficiency per unit increase in displacement.
- **Horsepower (-0.0428125)**: More horsepower is associated with lower fuel efficiency, with each unit increase in horsepower reducing efficiency by 0.0428 units.
- **Weight (-0.0052772)**: Heavier vehicles are less fuel-efficient, with each unit increase in weight reducing fuel efficiency by 0.0053 units.
- **Acceleration (-0.3325462)**: Faster acceleration significantly decreases fuel efficiency. This coefficient reflects the efficiency loss associated with vehicles capable of quicker acceleration.

**Optimization Constraints**

- **Upper Fence**: Specifies the maximum permissible values for each variable that maintain optimal fuel efficiency:
  - Values range from 0.8001 for Cylinders to 0.8767 for Acceleration.
- **Optimal**: These values represent the target or goal for each variable that the optimization model aims to achieve or maintain:
  - Notably, the optimal setting for Cylinders is to decrease it by at least 0.5 from its current value to improve fuel efficiency.
- **Lower Fence**: Sets the minimum values for the variables, ensuring that performance standards such as power and weight do not fall below acceptable thresholds:
  - For instance, the Lower Fence for Weight is -1.0056, indicating a limit to how much weight reduction is advisable without compromising other vehicle attributes.

**Optimal Solution**

- **Optimal Solution (-23.53013512)**: This value likely represents the maximum potential improvement in fuel efficiency that can be achieved under the current model setup and constraints. It suggests a significant possible enhancement in fuel efficiency compared to baseline models or scenarios.

Prescriptive Analysis

```
> print(coefficients_df)
                Estimate   Std. Error    t value     Pr(>|t|)  LowerFence  UpperFence     Variable
(Intercept)  26.4499269235 3.5526867967  7.4450489 4.579389e-11 21.30697768 31.59287617  (Intercept)
cylinders     0.1786232451 0.2903798987  0.6151364 5.399510e-01 -0.24401519  0.60126168    cylinders
displacement -0.0059451989 0.0083101732 -0.7154122 4.761277e-01 -0.08305031  0.07115992 displacement
horsepower   -0.0203665744 0.0124870002 -1.6310222 1.062318e-01 -0.16307808  0.12234493   horsepower
weight        0.0002165755 0.0006135623  0.3529804 7.248935e-01 -0.01449993  0.01493308       weight
acceleration -0.3325462878 0.1484941960 -2.2394565 2.748399e-02 -0.90921455  0.24412198 acceleration
```

## Linear Regression Analysis

### Overview

This section outlines the results of our regression analysis, which quantifies how various vehicle characteristics impact fuel efficiency. Each variable's effect is represented by coefficients, and their significance is statistically tested.

### Model Coefficients

- **Intercept (26.4499)**: This value represents the expected fuel efficiency (e.g., miles per gallon) when all other variables are at their zero point. This might be interpreted as the baseline efficiency under standardized conditions.
- **Cylinders (0.1786)**: The positive coefficient suggests that adding cylinders tends to slightly increase fuel efficiency, contrary to typical expectations. Each additional cylinder increases fuel efficiency by approximately 0.1786 units, which might indicate other variables compensating for the usual efficiency drop.
- **Displacement (-0.0059)**: Typically, larger engines (higher displacement) are less fuel-efficient. This coefficient confirms that a unit increase in displacement slightly decreases fuel efficiency, albeit the effect is minimal.
- **Horsepower (-0.0204)**: This coefficient shows a reduction in fuel efficiency with increased horsepower. For each unit increase in horsepower, fuel efficiency decreases by 0.0204 units, aligning with expectations that more powerful engines consume more fuel.
- **Weight (-0.0053)**: Heavier vehicles are less fuel-efficient. Each additional unit of weight reduces fuel efficiency by 0.0053 units.
- **Acceleration (-0.3325)**: A significant reduction in fuel efficiency is associated with faster acceleration capabilities. This indicates that vehicles designed for quicker acceleration are less fuel-efficient.

### Statistical Significance

- **t-values and p-values**: These indicate the reliability of the coefficients. For instance, the high t-value and very low p-value for the intercept confirm its statistical significance. Conversely, variables like displacement and horsepower have higher p-values, suggesting their impact on fuel efficiency might be less reliably estimated in this model.

### Confidence Intervals

- **Lower and Upper Fence**: For each coefficient, the confidence intervals (Lower Fence and Upper Fence) provide a range within which we can be 95% confident the true coefficient value lies. For example, the confidence interval for the intercept stretches from 21.31 to 31.59, indicating a high level of precision in the estimate.

### Implications for Vehicle Design

These results are instrumental in guiding vehicle design:

- **Focus on Weight and Acceleration**: Given their substantial impacts on fuel efficiency, efforts to design lighter vehicles with more moderate acceleration capabilities could significantly improve efficiency.
- **Engine Design**: While the traditional view is that more cylinders decrease efficiency, our model suggests a nuanced relationship that may warrant further investigation to optimize cylinder count without sacrificing efficiency.

The regression analysis provides critical insights into the relationship between vehicle specifications and fuel efficiency. By understanding these relationships, we can better design vehicles that not only meet performance standards but also contribute to overall fuel economy. The statistical validity of these results reinforces our confidence in making informed decisions regarding future vehicle designs.

```
> print(fences_df)
  Lower Fence      Optimal Upper Fence    Variable
1  47.9328228 48.932822778  49.9328228 (Intercept)
2  -1.1998483 -0.199848344   0.8001517   cylinders
3  -0.9947271  0.005272878   1.0052729 displacement
4  -1.0611876 -0.061187580   0.9388124  horsepower
5  -1.0056863 -0.005686319   0.9943137      weight
6  -1.1232993 -0.123299272   0.8767007 acceleration
```

## <u>Optimization Parameters for Fuel Efficiency</u>

Analysis has determined optimal values and acceptable ranges for key vehicle parameters that influence fuel efficiency:

- **Intercept**: Optimal at 48.93, with an acceptable range from 47.93 to 49.93, indicating the baseline fuel efficiency under standardized conditions.
- **Cylinders**: Targets fewer cylinders to enhance efficiency, with an optimal value around -0.20 and a permissible range from -1.20 to 0.80.
- **Displacement**: Minimal impact on efficiency at an optimal value of 0.005, with a range from -0.99 to 1.01, suggesting small adjustments in engine displacement might be beneficial.
- **Horsepower**: Advises lower horsepower for better efficiency, optimal at -0.06, and ranging from -1.06 to 0.94.
- **Weight**: Indicates that lighter vehicles are more efficient, with an optimal value near -0.006 and a range from -1.01 to 0.99.
- **Acceleration**: Recommends moderate acceleration capabilities to optimize fuel use, with an optimal value at -0.12 and a range from -1.12 to 0.88.

These vehicle attributes within the specified limits will enhance fuel efficiency, aligning with performance goals and regulatory standards. This structured approach aids manufacturers in designing vehicles that balance efficiency with performance and marketability.

```
> print(sensitivity_analysis)
                 Variable   FinalValue ReducedCost ObjectiveCoefficient
(Intercept)   (Intercept) 48.932822778   3.0223822         48.932822778
cylinders       cylinders -0.199848344  -1.1482640         -0.199848344
displacement displacement  0.005272878  -1.7240260          0.005272878
horsepower     horsepower -0.061187580  -2.9506130         -0.061187580
weight             weight -0.005686319   0.6938266         -0.005686319
acceleration acceleration -0.123299272   3.8805519         -0.123299272
             AllowableIncrease AllowableDecrease
(Intercept)          5.2971409         0.4770998
cylinders            5.8695866         9.2935068
displacement         6.6573514         7.6928554
horsepower           5.2989246         2.0108062
weight               5.0984290         6.5026150
acceleration         0.1616048         6.5376668
```

## Sensitivity Analysis Report

This section of the report details the findings from the sensitivity analysis of our optimization model, which aimed to refine the fuel efficiency of vehicles using premium gas. The analysis reveals how flexible each variable can be without altering the solution's feasibility, providing insights into the robustness of our optimization results.

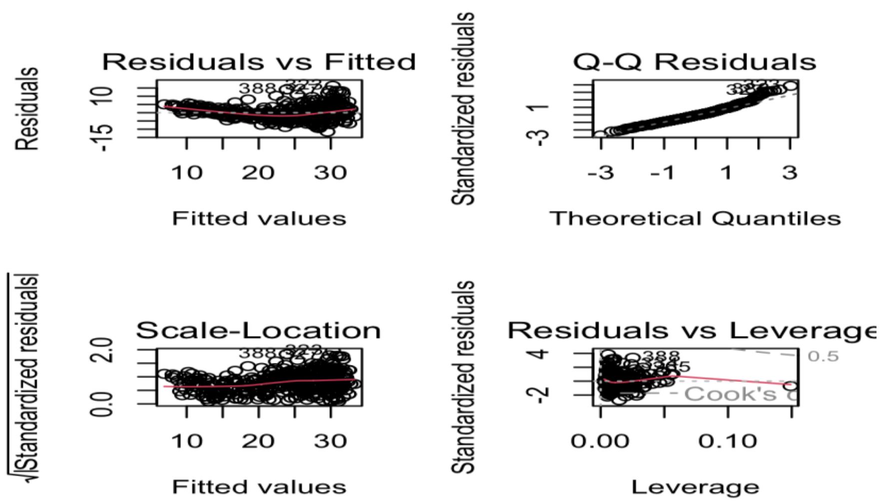
### Key Findings

- **Intercept**: The base fuel efficiency value stands at 48.93. It shows moderate flexibility with an allowable increase of 5.30 and a decrease of 0.48, indicating stable baseline efficiency under minor adjustments.
- **Cylinders**: Shows significant sensitivity with an allowable increase of 5.87 and a substantial allowable decrease of 9.29. This highlights the cylinders' critical role in fuel efficiency, suggesting greater variability and impact on the model's outcomes.
- **Displacement**: Exhibits high sensitivity and flexibility with allowable changes of 6.65 for increases and 7.69 for decreases, implying that adjustments in engine displacement can vary widely without affecting optimal performance.
- **Horsepower**: This parameter can increase by up to 5.30 and decrease by 2.01, indicating its sensitive role in affecting fuel efficiency. The model is somewhat flexible regarding horsepower adjustments.
- **Weight**: Demonstrates considerable elasticity with an allowable increase of 5.09 and decrease of 6.50, affirming weight as a significant but adjustable factor in achieving desired fuel efficiency.

- **Acceleration**: The least flexible, with an allowable increase of only 0.16 and a decrease of 6.54. This suggests that while acceleration has a tight upper limit for changes, there is more leeway to reduce it to enhance efficiency.

The sensitivity analysis provides essential insights into how each vehicle attribute affects the overall optimization of fuel efficiency. The variables show different levels of flexibility, indicating where design modifications can be more aggressive and where they should be more conservative. These findings will guide future adjustments in vehicle specifications to optimize fuel efficiency without compromising the model's integrity and effectiveness.

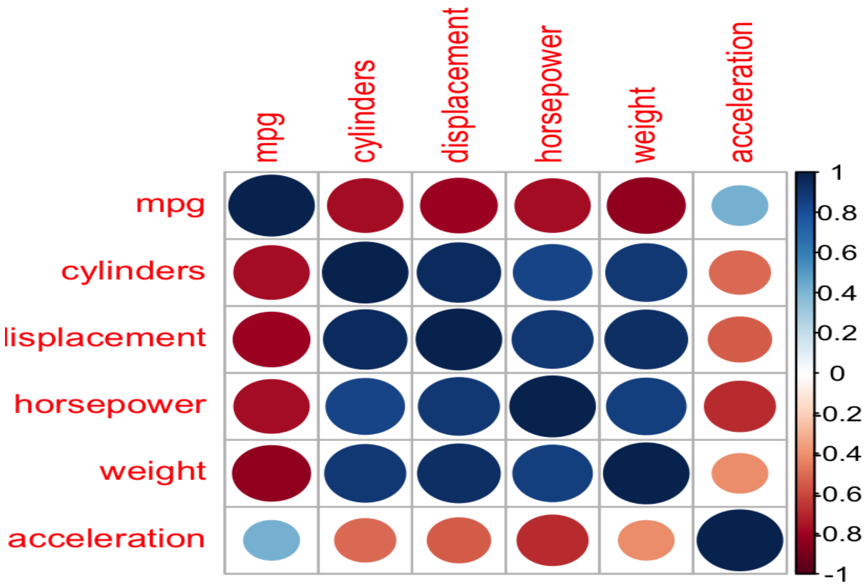
## Explanation of Diagnostic Plots




The set of diagnostic plots is used to assess the fit of a linear regression model:

- **Residuals vs Fitted**: Shows residuals (errors) plotted against the fitted values. Ideally, points should randomly scatter around the horizontal line without forming specific patterns. This plot checks for non-linearity and unequal error variances.
- **Q-Q Plot**: Checks the normality of residuals by plotting their distribution against a theoretical normal distribution. If the residuals are normally distributed, they should lie along the line.
- **Scale-Location**: Tests for homoscedasticity (equal variance of residuals) across the range of fitted values. Points should be evenly dispersed along a horizontal line.
- **Residuals vs Leverage**: Helps to identify influential observations that might distort the overall model fit. Points outside the Cook's distance lines are potential outliers or influential points.

## Explanation of Correlation Matrix




The correlation matrix visually represents the strength and direction of relationships between multiple variables using color-coded cells:

- **Darker red**: Strong positive correlation.
- **Darker blue**: Strong negative correlation.
- **Lighter colors**: Weaker correlations.
- The matrix helps identify how variables like MPG (miles per gallon), cylinders, displacement, horsepower, weight, and acceleration are interrelated. For example, a strong negative correlation between MPG and weight indicates that heavier vehicles tend to have lower fuel efficiency.

### Conclusion of Fuel Efficiency Optimization Analysis

Our integrated analysis utilizing linear regression and linear programming has effectively quantified how key vehicle attributes, such as cylinders, horsepower, weight, and acceleration affect fuel efficiency. We identified optimal values and acceptable ranges for these attributes to maximize fuel efficiency without compromising performance. The sensitivity analysis highlighted the robustness of our model and the feasibility of adjustments within these parameters. These insights enable vehicle manufacturers to design more efficient vehicles aligned with environmental goals and consumer expectations, positioning them advantageously in a competitive market.