

Statistical Modeling of Fuel Consumption of Selected Automobile Makes

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Abstract

Six automobile makes (Mercedes Benz, GM, BMW, Hyundai, Kia and Toyota) were compared for fuel efficiency. A total of 352 automobiles were involved in the study. Fitted model is analysis of covariance model with distance covered per gallon of gasoline as the response variable and engine capacity as the quantitative independent variable. Qualitative factors in the model are automobile make, drive description, air aspiration method and transmission mode. Toyota was found to be most fuel efficient, followed by Mercedes Benz, then Hyundai, GM, BMW and lastly, Kia. A comparison of drive description types revealed that 2-wheel (front) automobiles performed best, followed by 2-wheel (rear), All-wheel and lastly, 4-wheel. Turbo charged automobiles were found to be most fuel efficient, followed by naturally aspirated ones and lastly, supercharged. Automobiles equipped with manual transmission were more fuel efficient than those equipped with automatic transmission. Future research could include more vehicles and more recent models.

Keywords: Model, Fuel efficiency, Transmission, Toyota, Drive description, Gasoline.

Introduction

Automobiles are a very prominent means of transportation all over the world. Some are used for conveying humans while others are for conveying goods. Some are designed just for sports. Those for humans are either for family use or for commercial use. They vary in sizes depending upon the intended purpose. Owing to this fact, there exist sport utility vans, buses of various sizes, trucks, sport cars, Jeeps and so on. Regardless of the class an automobile belongs, achieving optimal utilization of fuel is the desire of every manufacturer as such remains one of the factors buyers consider when deciding on choice of automobile to acquire. Although this is coupled with a number of other considerations like purpose for buying, place of domicile, economic capacity, maintainability, durability, second hand value and so on.

Fuel efficiency, measured in terms of quantity of fuel consumed by a vehicle is of great importance since fuel is essential for the vehicle to move from one point to the other. All internal combustion engines produce energy by burning fuel like petrol, gas, and diesel and so on. It is fuel that produces the energy required by automobiles, although electricity powered automobiles are becoming common. Fuel consumption and emission standards are set from time to time in the developed world. For instance, in the United States, the Corporate Average Fuel Economy (CAFE) standards for motor vehicles were significantly raised in 2012 for the first time in almost three decades. The standards now call for an average across manufacturers of 54.5 miles per gallon (mpg) for new passenger cars by 2025. The light truck standards, which include minivans and sport utility vehicles, call for fuel economy levels of 31 mpg in 2021 and of 40 mpg in 2025 (Lipman, 2017). It is doubtful whether such standards exist in developing economies and even if they do, they cannot be strictly adhered to. This is because many developing economies, Nigeria inclusive rely on second hand

vehicles from the developed world as the cost of new ones can be afforded by only a few. The developing economies hence, seem to have little or no choice but to consume second hand vehicles most of which have failed environmental standards tests of their countries of origin before exportation. Unfortunately, this may have to continue for as long as poor countries are not led by selfless, competent leaders.

Fuel consumption has been modeled from different perspectives. Faris, Rakha, Kafafy, Idres and Elmoselhy (2011) classified fuel consumption modeling into five categories: Scale of the input variables-based modeling; formulation approach-based modeling; type of explanatory variable-based modeling; state variable value-based modeling and number of dimensions-based modeling. They further divided formulation approach-based modeling into analytical, empirical, statistical, and graphical modeling. The statistical approach is the main thrust of this article. A lot of researches have adopted statistical approach in modeling fuel consumption as a function of some automobile engineering characteristics.

Newman, Alimoradian, and Lyons (1989) presented a statistical and data-based fuel consumption model that uses average speed, engine displacement, and vehicle mass to predict fuel consumption for petrol and diesel trucks. They found that the vehicle mass is the term that dominates the influence on fuel consumption. Rizzotto, Lo Presti, Di Marco, and Lanzafame (1995) presented a data-based fuzzy logic bus fuel consumption model. Ahn (2002) proposed statistical regression models that predict vehicle fuel consumption and emission rates with key input variables of instantaneous vehicle speed and acceleration measurements; Smit and McBroom (2009) presented the development of a statistical high-resolution traffic emissions and fuel consumption average speed model.

Other contributions to the literature on fuel consumption modeling include Daw, Green, Thomas, Kennel, Finney, and Connolly (1996), Al-Momani and Badran (2007); Ahn and Rakha (2008); Togun and Baysee (2010); Lee, Park, Jung, and Yoo (2011); Wu and Liu (2012); Ben-Chaim, Shmerling and Kuperman (2013); Zhou, Jin, and Wang (2016); Ehsani, Ahmadi, and Fadaei (2016). More recent contributions are Fontaras, Zacharof, and Ciuffo, (2017); Ha, Choi, Lee, and Choi, (2019); Yao, Zhao, Zhang, Chen and Rong (2020) and Li et al. (2021).

While some research works on fuel efficiency modeling have focused on external factors like road terrain, operating temperature and traffic intensity and so on, others concentrated on automobile engineering specifications like, weight, acceleration, engine revolution per minute and tyre pressure and so on. There is need to compare different automobile makes based on well known specifications like engine capacity, air aspiration method, drive description and type of transmission. Findings from such can provide a guide to would-be buyers of automobiles on choice to make. This is the gap this article intends to fill.

The rest of the article is organized as follows: Section 2 presents Methodology while Section 3 presents Results and Discussion. The last section concludes the article.

Methodology

Data

Data were sourced from www.fueleconomy.org and they describe distance covered (in mile) per US gallon of gasoline, engine capacity, drive description, air aspiration method and transmission mode of 2010 models of Mercedes Benz, GM, BMW, Hyundai, Kia and Toyota automobiles. They consisted

of 42 Mercedes Benz, 134 GM, 84 BMW, 21 Hyundai, 26 Kia and 45 Toyota automobiles making a total of 352. Fuel efficiency is directly related to number of miles covered by US gallon of gasoline.

Model

The model entertained is one in which the dependent variable, distance covered (in miles per gallon of gasoline) is a function of engine capacity, automobile make (Mercedes Benz, GM, BMW, Hyundai, Kia and Toyota), drive description (2-wheel (front), 2-wheel (rear), 4-wheel and All-wheel), air aspiration method (supercharged, turbo charged and naturally charged) and transmission mode (automatic and manual). Automobile make, drive description, air aspiration method and transmission mode being qualitative factors were represented by dummy variables. The last of categories indicated against each qualitative factor was suppressed as usual to avoid dummy variable trap. That is, Toyota, all-wheel, natural aspiration and manual transmission respectively. The automobiles consisted of 2 German automobiles (Mercedes Benz and BMW), 2 Japanese (Toyota and GM) and 2 South Korean automobiles (Hyundai and Kia). This was deliberate to allow for some comparison.

The model is the analysis of covariance model

$$\hat{y}_i = \hat{\beta}_0 + \sum_{i=1}^{12} \hat{\beta}_i x_i \quad (1)$$

where

y= Distance covered in miles per Gallon of gasoline

x₁= Engine capacity

x₂=1 for Mercedes Benz

o for others

x₃= 1 for GM

o for others

x₄= 1 for BMW

o for others

x₅= 1 for Hyundai

o for others

x₆= 1 for Kia

o for others

x₇=1 for 2-wheel drive (rear)

o for others

x₈=1 for 2-wheel drive (front)

o for others

x₉=1 for 4-wheel drive

o for others

x₁₀=1 for supercharged aspiration method

o for others

x₁₁=1 for turbo charged aspiration method

o for others

x₁₂=1 for automatic transmission

o for manual transmission

Results and Discussion

The fitted model is

$$\hat{y}_i = 29.2 - 2.49x_1 - 0.489x_2 - 1.19x_3 - 1.75x_4 - 0.914x_5 - 1.87x_6 + 0.946x_7 + 3.57x_8 - 0.039x_9 - 0.23x_{10} + 0.364x_{11} - 0.165x_{12} \quad (2)$$

It indicates that engine capacity is a strong determinant (p-value=0, see Table 1) of distance covered and hence, of fuel consumption. For same make of automobile with same drive description, air aspiration method and transmission mode, an increase in engine capacity by 1 liter reduces distance covered per gallon of gasoline by average of 2.49 miles. Negative coefficients assumed by dummy variables representing automobile makes suggest that Toyota automobiles cover greater distances per gallon of gasoline than others holding engine capacity, drive description, air aspiration method and transmission mode constant.

On the average, Mercedes Benz covers 2.4927 miles less than Toyota per gallon of gasoline holding other variables constant (although the parameter is not significant, p-value>0.05); GM, BMW, Hyundai and Kia with same engine capacity, air aspiration method and transmission mode, respectively, cover 1.1874, 1.7547, 0.9139 and 1.8670 miles less than Toyota per gallon of gasoline. Toyota is hence, more fuel efficient than the five other automobile makes under consideration.

A comparison of drive description methods shows that 2-wheel drive (rear) and 2-wheel drive (front) are more fuel efficient while 4-wheel drive is less efficient than all-wheel drive automobiles, all other factors under consideration being constant. The 2-wheel drive (rear), 2-wheel drive (front) and 4-wheel cover on the average, 0.9459 mile, 3.5657 miles and 0.0394 mile more than all-wheel drive automobile respectively per gallon of gasoline.

Supercharged aspirated automobiles cover 0.227 mile less while turbo charged cover 0.3645 mile more per gallon of gasoline than naturally aspirated, holding other variables constant. Automobiles equipped with automatic transmission covers 0.1645 mile less than those equipped with manual, holding other variables constant. Manual transmission is hence, more fuel efficient than automatic transmission, all other factors being constant.

Coefficient of multiple determination of 70.9% obtained implies that variations in engine capacity, automobile make, drive description, air aspiration method and transmission mode explain 70.9% of variations in distance covered per gallon of gasoline.

Table 1. Parameter estimates and p-values

Predictor	Coefficient	SE Coef	T	p-value
Constant	29.2252	0.7906	36.97	0.000
X ₁	-2.4927	0.1451	-17.18	0.000
X ₂	-0.4894	0.6203	-0.79	0.431
X ₃	-1.1874	0.4713	-2.52	0.012
X ₄	-1.7547	0.5213	-3.37	0.001
X ₅	-0.9139	0.7111	-1.29	0.200
X ₆	-1.8670	0.6674	-2.80	0.005
X ₇	0.9459	0.5294	1.79	0.075
X ₈	3.5657	0.5662	6.30	0.000
X ₉	-0.0394	0.6878	-0.06	0.954
X ₁₀	-0.227	1.917	-0.12	0.906

X_{11}	0.3645	0.4456	0.82	0.414
X_{12}	-0.1645	0.3475	-0.47	0.636

The status of each variable in respect of significance is depicted in Table 1. Five of the 12 variables are significant at 5% level while others are not. Difference in fuel consumption between Toyota and each of GM, BMW and Kia is significant at 5% level while it is not so for Mercedes Benz and Hyundai.

Table 2. Analysis of variance

Source	DF	SS	MS	F	p-value
Regression	12	5915.20	492.93	68.99	0.000
Residual Error	339	2422.16	7.15		
Total	351	8337.36			

Table 2 presents results of model overall significance. The model is highly significant (p-value=0).

Table 3. Ranking based on automobile make

Automobile make	Rank
Mercedes Benz	2
GM	4
BMW	5
Hyundai	3
Kia	6
Toyota	1

Fuel efficiency performances of the six automobile makes are shown in Table 3. These ranks are hinged on the assumption that engine capacity, drive description, air aspiration method and transmission mode of the automobiles are same. Toyota is simply the best and this confirms the confidence reposed in Toyota products among Nigerians. Japanese automobiles (Toyota and GM) have average rank of 2.5 while German automobiles (Mercedes Benz and BMW) have average rank of 3.5. South Korean automobiles (Hyundai and Kia) have average rank of 4.5. Japanese automobiles have clearly fared better than others. However, it is commendable that Hyundai, a product of South Korea being a relatively new entrant into automobile manufacturing is ranked third, lagging behind one Japanese and one German automobile.

Table 4. Ranking based on drive description

Automobile make	Rank
2-wheel (Front)	1
2-wheel (Rear)	2
All-wheel	3
4-wheel	4

Table 4 ranks the drive description types on the assumption that engine capacity, automobile make, air aspiration method, and transmission mode are same. The best is the 2-wheel (front). This is understandable since transmission takes place at a point closer to the engine location unlike 2-wheel (rear) where transmission takes place at the rear. The improved fuel efficiency of 2-wheel (front) over 2-wheel (rear) is responsible for its preference by automobile manufacturers and consumers.

Table 5. Ranking based on air aspiration method

Turbo	1
Super charged	3
Natural	2

Turbo charged method proves to be best. A serious disadvantage of turbo charged engines is higher potential for overheating. Most automobiles in Nigeria are naturally aspirated and this seems reasonable as it is easier to repair and maintain and possesses less potential for overheating than others.

Conclusion

This article models and compares fuel efficiencies of 6 selected automobiles based on some engineering specifications. The study finds that Toyota is most fuel efficient, followed by Mercedes Benz, then Hyundai, GM, BMW and lastly, Kia. 2-wheel (front) automobiles are the best, followed by 2-wheel (rear), All-wheel and lastly, 4-wheel. Turbo charged automobiles are most fuel efficient, followed by naturally aspirated ones and lastly, supercharged. Automobiles equipped with manual transmission are more fuel efficient than those equipped with automatic transmission. These findings could serve as a guide to would-be automobile buyers. Future research could include more vehicles and more recent models.

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