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Comparative Analysis and Statistical Optimization of Fuel Economy for Sustainable Vehicle Routings

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Abstract: In this 21st century, there has been an increase in the usage of renewable products for the economic drifting of vehicle transportations systems. Furthermore, due to recent trends in climate change, researchers have started focusing on statistical optimization techniques for sustainable vehicle routings. However, until now, a major gap has been noticed in the multidomain statistical analysis for optimizing the parametric levels of the vehicle fuel economy. Therefore, in this research work, two widely utilized cars (Toyota and GMC Yukon) are considered on a particular route of Jeddah for the collection of the fuel economy data under the realistic conditions of air conditioner temperature, traffic patterns, and tire pressure. The outcomes of the factorial design of the experiment highlight that the fuel economy is optimal under the low air conditioner temperature, light traffic patterns, and 34 PSI tire pressure. Three replications of the fuel economy have been considered, and the statistical significance of the correlated variables has been justified by implementing the analysis of variance (ANOVA) approach on the various levels of fuel economy. During the analysis, the statistical hypothesis for random exogenous factors has been developed by incorporating a multivariate regression model. The outcomes highlight that both air conditioner temperature and traffic patterns in Jeddah have a significant negative effect on fuel economy. Results also depict that the effect of air conditioner temperature, traffic patterns, and tire pressure is substantially higher for heavy-engine automobiles such as the GMC Yukon compared to light-engine cars (Toyota Corolla). Furthermore, a normality test has also been considered to validate the outcomes of the proposed model. Therefore, it is highly recommended to utilize the proposed methodology in optimizing the trends of fuel economy for sustainable vehicle routings. Based on the findings of multidomain statistical analysis, it is also highly recommended the utilization of the Toyota Corolla car model for investigating the correlation of external undeniable factors (braking frequency, metrological conditions, etc.) with the trends of vehicle fuel economy.

Keywords: fuel economy; sustainable vehicle routings; 2^3-factorial design; correlated factors; ANOVA; multivariate regression

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1. Introduction

With the recent advancements in the automobile industry, researchers have been considering prominent statistical methods to evaluate fuel consumption for enhancing economic efficiency. Interestingly, the in-depth literature on fuel consumption has provided a roadmap to the scientific community for analyzing the efficiency of the fuel under the dynamic variations in the inherent parameters of the vehicle [1–3]. Additionally, different attributes of the scientific studies have been considered to uplift the transportation-sustainable development systems. Researchers have comprehended that vehicle fuel consumption is highly correlated by the traffic patterns, speed of the car, weather conditions, road-graded characteristics, and inherent properties or models of the deliberated vehicle [4,5]. Prominently, the demand for nonrenewable energy is also expected to increase by 36.5% in the next 5-year period from 2019–2024; however, this growing demand is particularly associated with the petroleum products of the automobile industry [6,7]. Therefore, researchers have been considering fuel economy to develop an interaction between renewable and nonrenewable energy sources for environmental sustainability [8,9]. Besides, the estimated integration between renewable and nonrenewable energy for petroleum products has shifted major attributes of global policy toward the contentment of fuel economy [10]. Furthermore, the conventional utilization of nonrenewable energy sources also depicts the emissions of uncertain gases that indirectly have major health concerns as well as environmental issues (Climate Change). Importantly, researchers have also notified that in this 21st century it is quite difficult to completely incorporate renewable energy sources into the automotive industry [11,12].

Consequently, the scientific community has been considering different statistical models for the assessment and prediction of the nonrenewable petroleum trends in the betterment of sustainable transportation systems [13]. In this regard, fuel economy enlightens the automobile efficiency of consumption in petroleum products and is expected to have a substantial impact in reducing adverse environmental effects [14,15]. Additionally, at the individual and firm level, the focus on fuel economy is also likely to create substantial benefits in terms of the expected reduction in vehicle operating costs [16,17]. A critical aspect in the attainment of fuel economy has been considered to evaluate the performance of the factors that influence automobile fuel consumption. Interestingly, there are several empirical research studies in which researchers have surveyed the correlated data of environmental and technical factors for the economic efficient vehicle transportation [18–20]. Researchers have established a systematic review design for the performance evaluation of automobiles in the United States (US). Researchers have highlighted that the type of fuel, car design, weight of the vehicle, and engine performance have a significant impact in determining the fuel consumption of automobiles [21,22]. On the other hand, experimental data from three Vauxhall Cavalier cars (1300 cc, 1600 cc (petrol), and 1600 cc (diesel)) have been collected and analyzed by incorporating the statistical technique of factorial analysis. Based on the established analysis, researchers have enlightened that the trends in fuel consumption primarily varied with the urban and suburban motorway environments [23]. Apart from that, different inherent parameters such as traffic patterns, tire pressure, car speed, and the rate of gear change have also been noted to have a significant effect on fuel consumption for all three Vauxhall Cavalier automobiles [24–26]. The traffic patterns in Saudi Arabia have been comprehensively analyzed by considering a case study in which researchers have evaluated the environmental factors. They highlighted the limitations and inherent factors that may adversely affect sustainable transportation systems. Furthermore, based on the outcomes, they have recommended the utilization of their designed study for investigating the performance of different vehicles under various environmental conditions [27]. Another aspect of the transportation system is noticed in which researchers have conducted a survey to analyze the usage of bicycles, and based on the outcomes, they have concluded that only 1.7% of bicycles have been specifically utilized for sustainable drives [28]. Additionally, researchers have also highlighted that in the suburban environment, the car throttle velocity could be a dominant variable to adversely affect the trends in fuel consumption [27,28]. Likewise, the primary survey design with 250 car drivers has been investigated in three major capital cities of Pakistan for the generation and collection of the empirical data. Interestingly, results revealed that car mileage, the extent of automobile maintenance (engine oil replacement), and the number of prior car drivers are inherently important factors that determine the rate of fuel consumption [29,30]. Similarly, researchers have numerically investigated the advanced driving assistance systems (ADAS) with over 100 drivers, and results have been compared with the available outcomes of the afore-explained methodology [31,32]. Essentially, they found that the amplitude of vehicle acceleration and automobile speed would potentially affect the consumed liters of fuel. Furthermore, a comprehensive assessment of the fuel consumption is also studied in which researchers have investigated the levels of fuel consumption in terms of various environmental factors. The external factors such as altitudes, air pressure, and wind speed have an acceptable impact on the desired fuel economy. However, it is also highlighted that the statistical models usually consider such external variables as random factors because of their inaccessibility and dynamic abruptness [33,34]. In this regard, several research studies have also been studied to manipulate these coherent variables in the optimization of consumed fuel trends for better visualization and evaluation of sustainable economic automobiles [35–37]. Additionally, researchers have also found a strong correlation between tire pressure and fuel consumption. Results have also indicated that fuel consumption can be decreased up to approximately 5.2% with the increase in tire pressure by 1 pound per square inch (PSI). In the recent past, the technical aspects of engine oil have been considered to analyze vehicle performance, and it is noted that 5–20 W engine formula (type of oil) would be best suited for increasing fuel efficiency [38,39].

The findings of the above-described vehicle transportation methodologies have been limited by certain empirical laws, and a major gap has been seen in the multidomain validated statistical optimization for vehicle fuel economy. Limited research has also been observed in the individual contributions of the correlated input factors toward the attainment of the desired fuel economy. The proposed work highlights the significance of the integrated statistical approach by implementing the factorial design of the experiment, analysis of variance, and multivariate regression model on the realistic data of the vehicle fuel economy. The outcomes of the factorial design of the experiment have highlighted that fuel economy is optimal under the low air conditioner temperature, light traffic patterns, and 34 PSI tire pressure. Analysis of variance has been utilized to justify the statistical outcomes and highlight the statistically correlated input factors of the model. A multivariate regression model is also incorporated to investigate the individual influence of correlated input factors on the response variable (fuel economy). A normality test has been included to validate the statistical outcomes, and it is concluded that the correlated factors have more influence on the fuel economy of the GMC Yukon as compared to that of the Toyota car model. Based on the results obtained, it is highly recommended to utilize the proposed methodology in analyzing the correlation between the factors affecting the vehicle fuel economy.

2. Materials and Methods

Over time, the demand for fuel usage has been increasing in the multiple domains of the energy sector. In the recent past, women have also been allowed to drive in Saudi Arabia. Apart from the advantageous nature of this action, fuel consumption has also drifted due to the overall increase in the utilization of vehicles. Researchers have been focusing on the dynamic trends of fuel consumption (in liter per capita) for a better understanding of sustainable transportation systems. Additionally, consumption per capita is one of the promising factors for the economic analysis of domestic resources depletion. Therefore, at first, statistical data have been interpreted for a couple of years (2010 to 2019) to analyze the fuel consumption, as shown in Figure 1. It is observed that after the year 2016, fuel consumption increased exponentially, and particularly in 2019, 3.58 L/capita was consumed in normal vehicle routings. Therefore, over the past few years, researchers have started exploring statistical optimization techniques to investigate the influence of promising factors on vehicle fuel consumption [40,41]. Additionally, the rising trends of Figure 1 also enlighten the major issue of economic exhaustion in transportation.

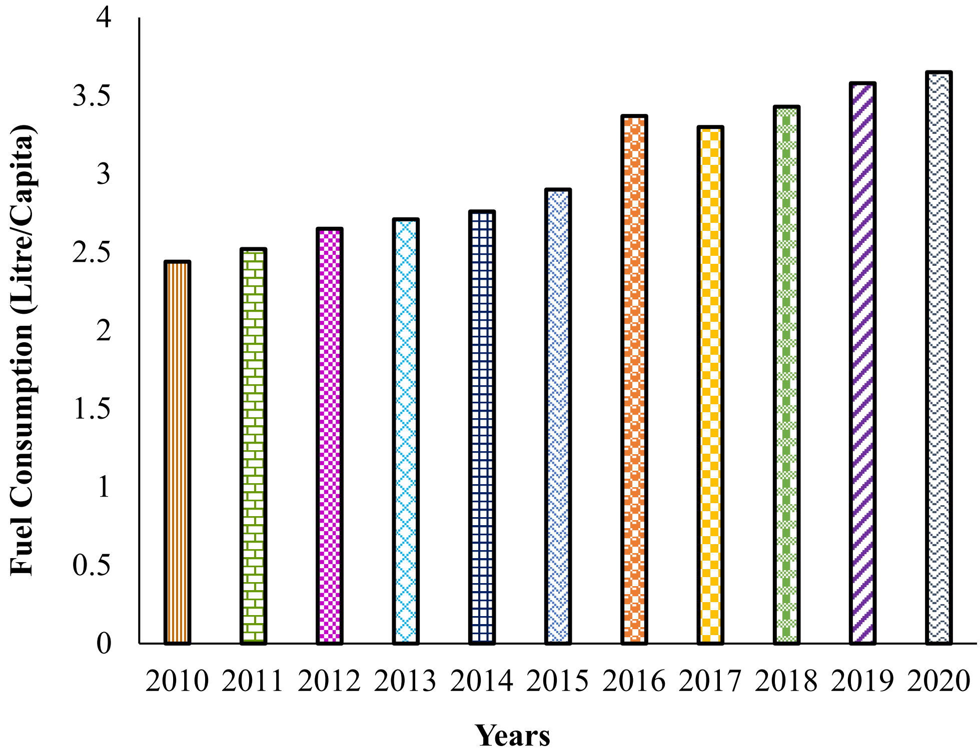

Figure 1. Fuel Consumption vs. Years in Saudi Arabia.

Due to the abovementioned major economic issues, in this research work, two commercially available car models, Toyota Corolla and GMC Yukon, have been utilized to collect real data for the estimation and optimization of the fuel economy parameters. The experiments were performed in Jeddah, Saudi Arabia by incorporating a distance of 28.4 km between two different gas stations (X and Y), as shown in Figure 2.

Figure 2. Geographic location of the experimental study design.

The desired data were generated by measuring the fuel economy in terms of kilometer per liter under the different scenarios of AC temperature, tire pressure, and traffic patterns. Nevertheless, acceptable data related to fuel consumption have been available in the literature; however, the emerging trends in the sustainable vehicle driving system have urged researchers to gather the data for multiple modern vehicles. Therefore, the proposed methodology will provide a comprehensive investigation of the inherent factors that highly influence fuel economy. Noticeably, the GMC Yukon car model has a heavy engine and a better compressor as compared to the Toyota Corolla car model; however, during the real-time scenarios, tanks of both the aforementioned cars were filled with the same levels of fuel. It must be noted that initially, both the cars traveled from gas station X to gas station Y to attain the one route. Afterward, cars traveled back to gas station X to cover the collective distance of 24.5 km. Importantly, the same driver was utilized to collect the data from the above-described routes. Therefore, the data have not only provided us with a descriptive way of analyzing the fuel economy, but have also maintained the significance level of the experimental study. Furthermore, in the literature, limited research has been seen on the inherent parameters of the aforementioned vehicles that indirectly impact the fuel consumption; therefore, in this research work, the factorial design of the experiment has been implemented to ascertain the desired features of the model. Additionally, the fuel economy is usually evaluated by measuring the distance covered in a liter fuel, and therefore, in this research work, the fuel economy has been selected as a response variable to highlight the significance of the proposed design of experiments. Figure 3 shows concise yet effective steps of the proposed methodology for analyzing the primary factors of the fuel economy.

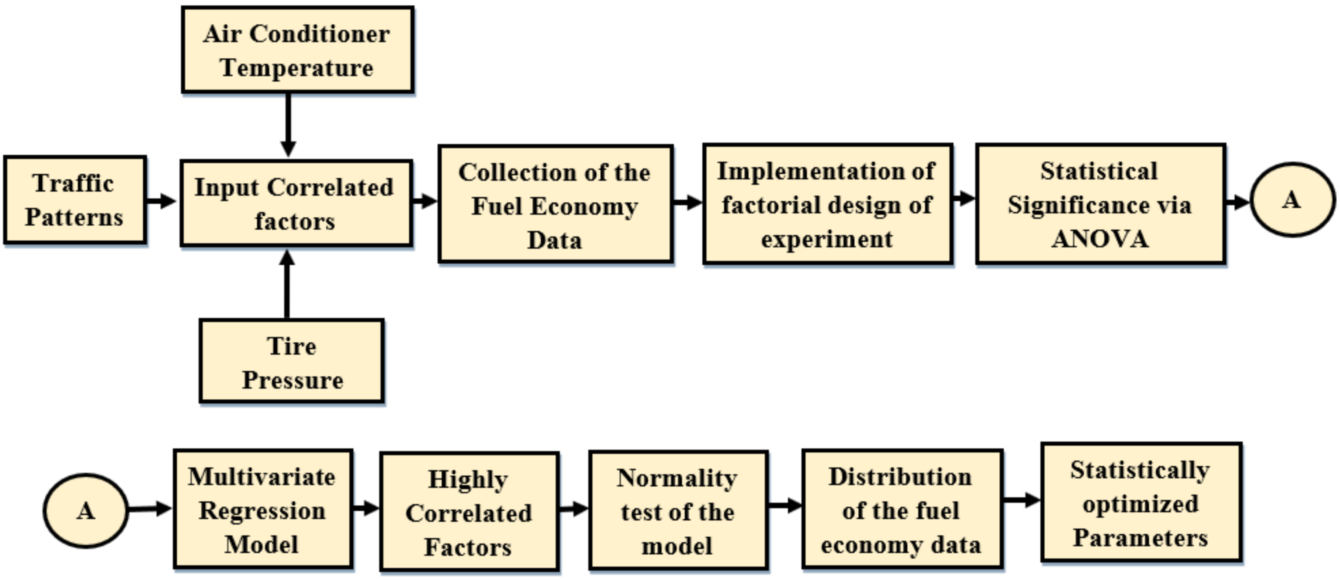

Figure 3. Major steps for the proposed methodology.

Study Variables and Collection of Data

Different research-oriented hypotheses have already been available in the literature for investigating the correlation between multiple input factors. Additionally, theoretical interpretations of the fuel economy have shown promising interests in the exploration of the vehicle's variables for optimal and sustainable driving. Therefore, the design of the experiments was implemented by incorporating three controllable factors: air conditioner temperature, tire pressure, and traffic patterns. The fuel consumption (kilometer per liter) was considered a response variable of the proposed model. Additionally, during the collection of the data, it was observed that certain undeniable factors such as weather conditions, braking frequency, and acceleration may influence the levels of fuel consumption. However, due to the nonlinearity, and unpredicted variations of the aforesaid factors, it is quite uncertain to consider them in the developed factorial design of the experiment. Therefore, these factors are known as random factors, and their influence on the response variable has been considered by developing certain theoretical hypotheses. Table 1 comprises the input factors along with levels of the proposed model.

Table 1. Input factors of the design study.

Input Factors	Parametric Symbol	Low Level	High Level
Air Conditioner (AC) Temperature	A	Off	On
Traffic Patterns	B	Light	Heavy
Tire Pressure (PSI)	C	28	34

However, it is noteworthy to highlight that under the aforesaid design parameters, the design of experiments was repeated three times to increase the effectiveness of the model. Therefore, for each experimental run, the fuel economy was investigated by calculating the distance covered in a liter (fuel consumed).

The dynamic features of the model were incorporated by considering two nominal conditions of the traffic patterns. Therefore, the two car models were driven in both light and heavy traffic scenarios on the considered experimental route. During the data collection, it was observed that the heavy traffic pattern primarily occurred on the weekdays from 7:00 a.m. to 9:00 a.m. or 2:00 p.m. to 4:00 p.m. On the contrary, the light traffic patterns were seen during the weekends between 7:00 a.m. and 10:00 a.m. Additionally, the heavy traffic patterns were associated with a considerable level of acceleration and gear braking system. Conversely, less gear braking and smooth driving were noticed in the light traffic patterns. Therefore, it is highly recommended to change the driving strategies for smooth and efficient routings. However, the proposed methodology has noticeably provided a platform to establish the theoretical interpretations and correlation of the traffic patterns with the fuel economy. Similarly, the air conditioner (AC) temperature was considered to analyze the influence of the inherent temperature variations on the fuel economy. The low temperature was set at the point where the air conditioner was not utilized, while the high temperature was established at the point where the air conditioner operated with the highest thrust. However, this variation in AC temperature was solely dependent on the preferences of the driver. Apart from the internal factors, there were some external factors that affected the fuel economy, and in this research work, tire pressure was incorporated as a control factor variable to assess how tire pressure influences the level of fuel consumption. In the proposed model, the unpredicted factors were justified by establishing the statistical hypothesis, and it is recommended to consider those random factors (weather conditions, braking frequency, type, and model of car) in the optimization of the fuel economy. Figure 4 comprises the concise steps for the collection of the desired data under the various conditions of the control variables.

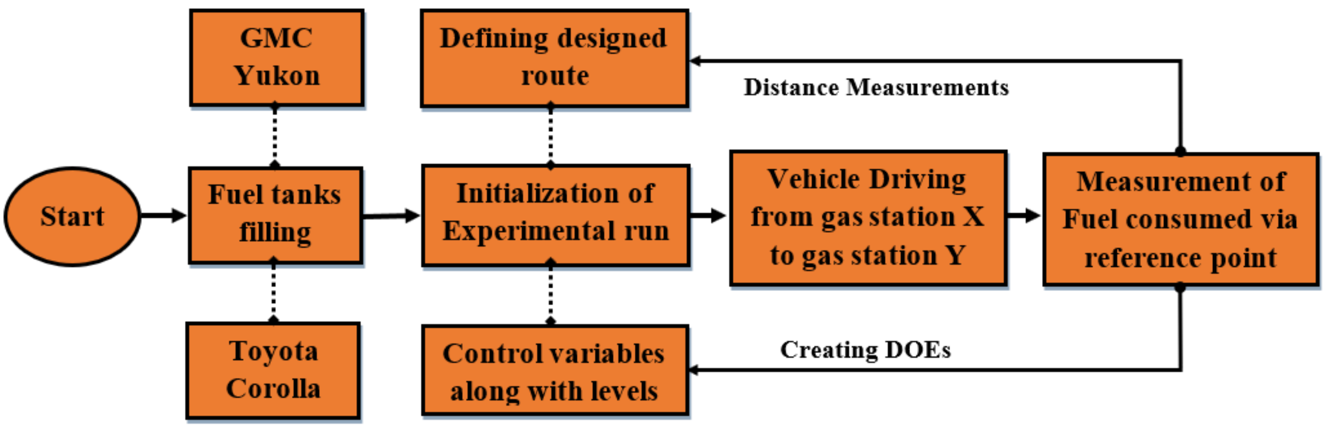

Figure 4. Major steps methodology for the desired data.

After the selection of the control variables, the fuel tanks of both cars were initially filled to the maximum level, and preliminarily distance in kilometers was noted for calculation of fuel economy, as given by Equation (1). Afterward, the driver followed the route to cover a distance of 28.4 km from gas station X to gas station Y, and after each experimental run, the fuel tank was refilled to determine the ratio of fuel consumed. The same procedure was repeated for both the cars and under the various conditions of the control variables.

3. Data Analysis

The established data have been further normalized to achieve the desired parametric features of the designed study. It must be noted that during the experimental runs, certain unrealistic conditions developed multiple outliers in the collected data; therefore, at first, a statistical normalized technique was utilized for the optimal generated data of the fuel economy. Afterward, different statistical on the design of experiments were presented to evaluate the performance of the control variables.

3.1. Factorial Design of Experiment

Over the past few years, researchers have been considering different statistical optimization techniques for multiple factors of vehicle fuel consumption. In this research work, MINITAB is utilized to implement the factorial design of the experiment (DOE) on the afore-described dataset. The correlation between statistically significant factors of the model has been analyzed by considering the theoretical interpretations of the proposed factorial analysis. Furthermore, researchers have been considering the full and fractional design of experiments to accurately determine the influence of input factors on the output response of the model. In this regard, the number of input factors along with their levels play a crucial role in the selection of the abovementioned categories. The proposed design model comprises three factors, and therefore, in this research work, 2^3 factorial design of experiment has been used to analyze the performance of the vehicles under the influence of different controllable factors. This particular design of experiment has carried eight variant experimental runs to interpolate the fuel economy under the considered levels of the traffic patterns, air conditioner temperature, and tire pressure. A detailed explanation of this experiment is incorporated in Section 4.1 of this manuscript.

3.2. Analysis of Variance

The different attributes of the factorial design of the experiment have been further justified by implementing an analysis of variance approach on the collected dataset. The analysis of variance (ANOVA) plays a crucial role in highlighting the dominant input parameters of the considered system. In this approach, level of significance and *p*-value are the two important parameters for statistically analyzing the correlated variables of the system. Therefore, the proposed model has been analyzed by considering a confidence interval of 95% [42,43]. Therefore, the *p*-value of statistically significant factors will always be less than the level of significance (5% = 0.05) [44], and in the proposed model, the *p*-value has further been utilized to select the dominant variable of the fuel economy. Additionally, in some cases, *p*-values of all the factors remain approximately the same, which, in turn, creates problems for the selection of most correlated factors. Therefore, researchers have been utilizing F-statistics to highlight the significance of the mean square error treatment. Consequently, the controllable factors having a greater value of F-statistics will be considered statistically significant [45,46].

In the proposed model, the fuel consumption was measured for each of the experimental runs, and this process was repeated three times to obtain replicates of the response variable. Therefore, analysis of variance approach has been integrated with 2^3 factorial designs of the experiment for determining the statistically significant factors of the proposed model. Figure 5 comprises a concise summary of the integrated design of the experiment.

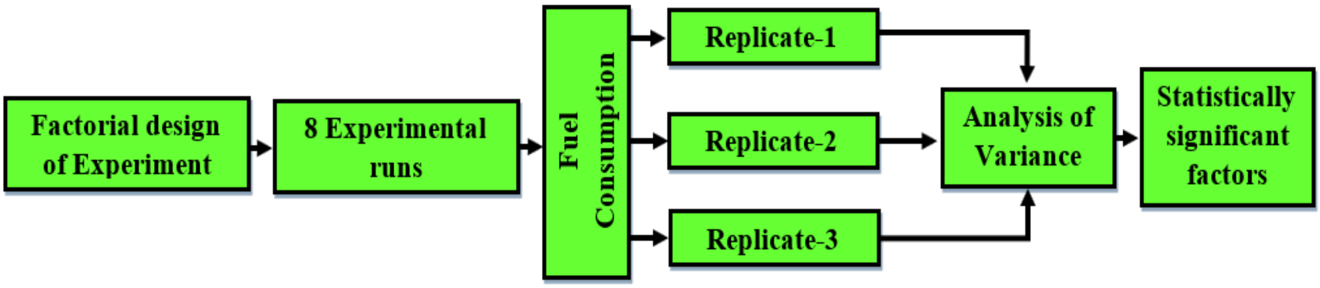

Figure 5. Integrated analysis based on factorial and ANOVA approaches.

3.3. Multivariate Linear Regression

During the collection of the data, optimal inherent parameters were considered to analyze the fuel economy of the two considered vehicles. Additionally, it is assumed that certain external or exogenous variables may also affect the levels of fuel consumption; therefore, the statistical hypothesis has already been proposed to incorporate those factors in the developed model. Furthermore, the different correlations between the factors have been noticed due to the implementation of the afore-described approaches (full-factorial and ANOVA) and the evaluation of the statistically significant factors. Therefore, MINITAB is further utilized to implement a new approach of multivariate regression on the desired dataset to predict the model estimator. Apart from that, multivariate regression has also helped us to incorporate the exogenous variables for the effectiveness of the proposed design of experiments. Therefore, Equation (1) highlights the variations in the response variable due to the inherent as well as external (environmental) factors.

$$\text{Fuel Consumption } (\hat{Y}) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \quad (1)$$

In Equation (1) the variables X_1, X_2, and X_3 represent the tire pressure, AC temperature, and the traffic condition, respectively, while β_1, β_2, and β_3 represent the respective exogenous variables' estimated coefficients. Similarly, the error term (ε) represents the random factors including the type of driver, braking frequency, car model, and acceleration levels, which are likely to influence the fuel economy of a car.

4. Results and Discussion

In this section, different statistical attributes of the proposed model are presented to investigate the fuel economy under the different levels of controllable factors. At first, results of the factorial design of the experiment are included to analyze the replications in the fuel consumption with the predefined orthogonal array (eight experimental runs). However, the factorial design of the experiment does not allow us to correlate the statistically significant factors; therefore, outcomes of ANOVA are included in Section 4.2 for performance evaluation of the individual factors. Finally, a comprehensive investigation of the multivariate regression approach is presented in Section 4.3 to justify the statistical interpretations of the correlated input factors.

4.1. Fuel Economy via Correlated Factors

In this research work, the ultimate objective is to select the optimal levels of the controllable factors for optimizing the vehicle fuel economy. This optimization was performed by 2^3 factorial designs of the experiment for correlating the input factors of the model. Table 2 comprises the fuel economy for the Toyota Corolla car model under the different conditions of the input factors. Three replications of the fuel economy were considered to avoid any human error, and therefore, the optimal average fuel economy of 20.42 km/L is obtained, as highlighted by Table 2. The aforesaid value of fuel economy was obtained under the light traffic patterns, low level of air conditioner temperature, and by considering 34 PSI tire pressure. This means that under the optimized levels of the controllable factors, the driver had economical traveling, which, in turn, reduced the levels of fuel consumption.

Table 2. The 2^3 Factorial Design Data Analysis for Toyota Corolla Car Model.

AC Level A	Traffic Pattern B	Tire Pressure C	Kilometers per Liter Replicate I	Replicate II	Replicate III	Average
Off	Light	28	18.750031	18.387097	17.48466258	18.02634
High	Light	28	16.37931	14.84375	15.15957447	15.15473
Off	Heavy	28	16.473988	15.240642	15.9217877	15.68041
High	Heavy	28	12.723214	12.23176	11.92468619	12.14989
Off	Light	34	19.127517	20.80292	20.35714286	20.41864
High	Light	34	16.764706	17.065868	16.66666667	16.85498
Off	Heavy	34	16.863905	17.272727	16.56976744	16.91488
High	Heavy	34	14.179104	13.380282	13.63636364	13.58285

The effectiveness of the model was further investigated by interpolating the fuel economy of the GMC Yukon Car Model. Likewise, a similar procedure was followed in the data collection, and Table 3 comprises the fuel economy for the GMC Yukon car under the different conditions of the input factors. Similarly, three replications of the fuel economy were considered to increase the model efficiency, and therefore, for this car model, the optimal average fuel economy of 10.28 km/L is obtained, as highlighted by Table 3. The aforesaid value of fuel economy was importantly attained under the light traffic patterns, low level of air conditioner temperature, and by considering 34 PSI tire pressure. Results also highlighted that both car models had optimal fuel economy under the same levels of the controllable factors, and due to this reason, it is highly recommended to employ the proposed model for the various models to reduce the levels of fuel consumption. Moreover, the outcomes also claim that under the same parametric values, and environmental conditions fuel economy of the Toyota car model is higher than that of the GMC Yukon car.

Table 3. The 2^3 Factorial Design Data Analysis for GMC Yukon Car Model.

AC Level A	Traffic Pattern B	Tire Pressure C	Kilometers per Liter Replicate I	Replicate II	Replicate III	Average
Off	Light	28	9.726962457	9.9650350	9.7269625	9.832772
High	Light	28	8.142857143	8.0508475	7.9387187	8.011236
Off	Heavy	28	8.482142857	8.3333333	8.2848837	8.328335
High	Heavy	28	6.968215159	6.7857143	6.8345324	6.827689
Off	Light	34	10.21505376	10.6741573	9.8958333	10.27722
High	Light	34	8.878504673	8.9622642	8.7692308	8.867165
Off	Heavy	34	8.584337349	8.6890244	8.5062500	8.596159
High	Heavy	34	7.289002558	7.5197889	7.1072319	7.310787

After analyzing the parametric influence on the fuel economy, three different conditions (C1:C3) were further considered to obtain the minimum, average, and maximum values of the fuel economy, as shown in Figure 6. The first parametric condition (C1) comprises the high air conditioner temperature, heavy traffic patterns, and tire pressure of 28 PSI, which, in turn, produces the lowest fuel economy of the Toyota car (12.14) and GMC Yukon (6.8). Similarly, the second parametric condition (C2) comprises the high air conditioner temperature, light traffic patterns, and tire pressure of 34 PSI, which, in turn, generates the average fuel economy of the Toyota car (16.8) and GMC Yukon (8.8). Finally, the third parametric condition (C3) comprises the low air conditioner temperature, light traffic patterns, and tire pressure of 34 PSI, which, in turn, highlights the optimal fuel economy of the Toyota car (20.4) and GMC Yukon (10.2). Additionally, under the predefined parametric levels, the Toyota car model showed promising fuel economy results as compared to GMC Yukon.

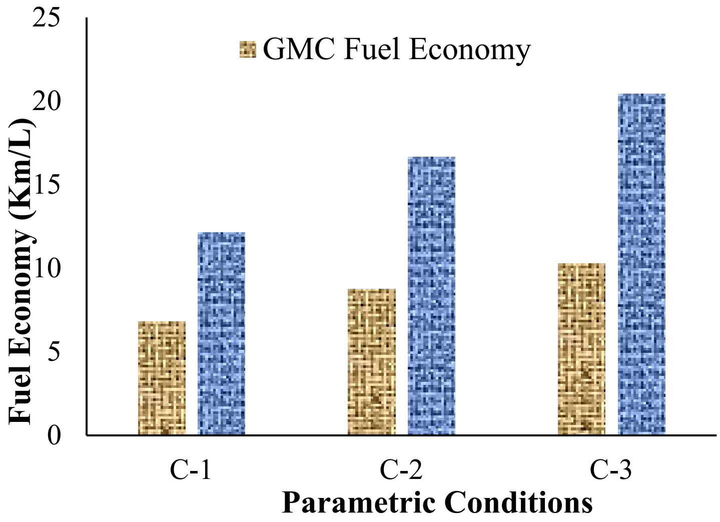

Figure 6. Levels of Fuel consumption via Parametric conditions (C1:C3).

4.2. Statistically Significant Factors

The factorial design of the experiment provided us the detailed theoretical interpretations of the fuel economy under the various levels of the input factors. However, it is quite unpredicted to ascertain the statistical significance of the factors. Therefore, ANOVA was integrated into the data analysis to establish the proportion of explained variance in fuel consumption. Additionally, the fluctuations, as well as mutual correlation, were also determined by ANOVA, which would help the scientific community to confidently consider the highly correlated factors. The proposed model was analyzed by considering a 95% confidence interval; therefore, the p-value of all the factors should be less than or equal to 0.05 to justify the outcomes of the factorial design of the experiment. Table 4 presents a summary of the ANOVA outcomes to facilitate assessment on whether the three independent factor variables and their corresponding interaction terms have any substantial influence on fuel consumption of the Toyota Corolla car model. Results depict that the linear model is statistically significant ($p = 0.004 < 0.05$), and in this case, individual contributions of the factors played a prominent role in obtaining the desired p-value of the model. Furthermore, it is noticed that air conditioner ($p = 0.008 < 0.05$), traffic pattern ($p = 0.003 < 0.05$), and tire pressure ($p = 0.001 < 0.05$) all had a substantial influence on fuel consumption for the Toyota Corolla car model. However, the most dominant input factor in the analysis of fuel economy was found to be the tire pressure, and this is due to its lowest p-value as compared to other controllable factors. Additionally, the outcomes also highlighted the most significant two-way interaction between traffic pattern and tire pressure of the model. On the contrary, all other interactions (two way and three-way) are statistically insignificant, as given in Table 4. In Equation (2), K represents the number of observations, and the mean square due to treatment is found by dividing the sum of squares due to treatments (SSTR) to the model degree of freedom (K − 1).

$$\mathrm{MSTR} = \frac{\mathrm{SSTR}}{\mathrm{K}-1};\ \mathrm{SSTR} = \sum\nolimits_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2 \tag{2}$$

Similarly, the mean square error is found by dividing the sum of squares due to error (SSE) to the desired observation, as given by Equation (3).

$$\mathrm{MSE} = \frac{\mathrm{SSE}}{n_T - k};\ \mathrm{SSE} = \sum_{j=1}^{k}(n_j - 1)s_j^2 \tag{3}$$

Table 4. Analysis of Variance for Toyota Corolla Car Model.

Source	Sq. Sum	DF	MS	F-Value	*p*-Value
Linear Model	124.125	3	41.375	122.07	0.004
A	62.868	1	62.868	185.48	0.008
B	50.530	1	50.53	149.08	0.003
C	10.727	1	10.72	31.65	0.001
A * B	0.720	1	0.72	182.13	0.164
A * C	0.045	1	0.045	0.13	0.72
B * C	0.583	1	8.5	150.1	0.04
3-Way interaction	0.640	1	0.64	1.89	0.188
A * B * C	0.640	1	0.64	1.89	0.188
Error	5.423	16	0.34	-	-
Total	131.536	23	-	-	-

* Explains the significant interaction between factors.

Likewise, Table 5 comprises tangible outcomes of ANOVA for the GMC Yukon car model to interpolate the statistical significance of all the three independent factor variables. The two-way interaction between traffic patterns and tires pressure were also noticed, as given by the last row of Table 5. Noticeably, in the proposed study, a linear model elaborates a constant rate of change between the input factors and a response variable. Results highlight that the linear model is statistically significant, having a *p*-value of 0.003 (less than the level of significance), and therefore, the developed model is justifying the statistical interpretations of the factorial design of the experiment. Results also depict that air conditioner ($p = 0.007 < 0.05$), traffic pattern ($p = 0.002 < 0.05$) and tire pressure ($p = 0.001 < 0.05$) all have a substantial influence on fuel consumption for the GMC Yukon car model. Similarly, as in the case of the Toyota car model, tire pressure is the most significant factor for efficiently optimizing the fuel economy of the GMC Yukon car model. Finally, a *p*-value of 0.03 was found for the two-way interaction between tire pressure and traffic patterns; therefore, it is highly recommended to incorporate both factors in the parametric evaluation of the vehicle's fuel economy.

Table 5. Analysis of Variance for GMC Yukon Car Model.

Source	Sq. Sum	DF	MS	F-Value	*p*-Value
Linear Model	27.758	3	9.25	263.42	0.003
A	13.858	1	13.858	394.53	0.007
B	12.272	1	12.27	349.39	0.002
C	1.628	1	1.628	46.34	0.001
A * B	0.019	1	0.019	0.56	0.466
A * C	0.077	1	0.077	2.19	0.158
B * C	0.086	1	0.086	130.1	0.03
3-Way interaction	0.031	1	0.031	0.88	0.361
A * B * C	0.031	1	0.031	0.88	0.361
Error	0.562	16	0.035	-	-
Total	28.53	23	-	-	-

* Explains the significant interaction between factors.

4.3. Outcomes of Multivariate Regression Analysis

The statistical significance of the input factors was enlightened by the outcomes of the above-described integrated design of experiments. However, the fuel economy was highly influenced by the individual input factors of the model. Therefore, multivariate regression analysis was carried out to estimate the correlation between the input factors and the response variable, as given in Table 6.

Table 6. Summary of the Multivariate Regression Analysis.

Variable	Toyota Corolla	GMC Yukon
Intercept	5.839	9.350
A	−1.345	−2.070
B	−0.096	−0.160
C	0.087	0.222
A * B	−0.119	−0.321
A * C	−0.101	−0.421
B * C	+0.021	+0.035
A * B * C	−0.678	−0.83

* Explains the significant interaction between factors.

Results highlight that the air conditioner (β_1 = −1.345) and the traffic pattern (β_2 = −0.096) have a significant negative effect on fuel consumption of the Toyota Corolla car model. Additionally, the negative effect of the above two stated variables on fuel consumption is substantially greater for the GMC Yukon car model as compared to the Toyota Corolla car model. On the other hand, tire pressure has a significant positive influence on fuel consumption for both the Toyota Corolla (β_3 = 0.087) and the GMC Yukon (β_3 = 0.222). Furthermore, in the two-way interaction, the tire pressure and traffic patterns (B * C) show positive influence in the multivariate analysis. Concludingly, the results are in well agreement and therefore satisfy the statistical significance of the proposed methodology. Based on the outcomes of multivariate analysis, regression models for both cars are finalized as given by Equations (3) and (4).

$$\text{Toyota Fuel Economy } (\hat{Y}) = 5.839 - 1.345\text{ A} - 0.096\text{ B} + 0.087\text{ C} - 0.119\text{ A} * \text{B} - 0.101\text{ A} * \text{C} + 0.021\text{ B} * \text{C} - 0.678\text{ A} * \text{B} * \text{C} \quad (4)$$

$$\text{GMC Fuel Economy } (\hat{Y}) = 9.350 - 2.070\text{ A} - 0.160\text{ B} + 0.222\text{ C} - 0.321\text{ A} * \text{B} - 0.421\text{ A} * \text{C} + 0.035\text{ B} * \text{C} - 0.83\text{ A} * \text{B} * \text{C} \quad (5)$$

Model Validation

During the analysis of the proposed model, certain assumptions on normality, linearity, and constant residual variance were considered to effectively investigate the statistical significance. However, in realistic scenarios, these assumptions may adversely affect the fuel economy; therefore, further analysis was carried out to evaluate and validate the results of a multivariate linear regression model.

Figure 7 shows the normal plot of standardized effects, which supports outcomes of both ANOVA and the multivariate linear regression analysis. In this normal plot, the standardized effects are analyzed by considering the positive and negative ranges as cleared from the *x*-axis of Figure 7. The results highlight that for both the car models, air conditioner (factor A) and traffic pattern (factor B) have significantly negative standardized effects on fuel economy. On the other hand, tire pressure (factor C) has a significantly positive standardized effect on the levels of fuel economy. Additionally, different outliers were been observed during the standardized analysis; however, their effects on the desired response are negligible, as clear from the circular patterns in Figure 7. Therefore, outcomes of the multivariate regression are in good agreement with the statistical interpretations of both the factorial design of the experiment as well as analysis of variance (ANOVA) approaches.

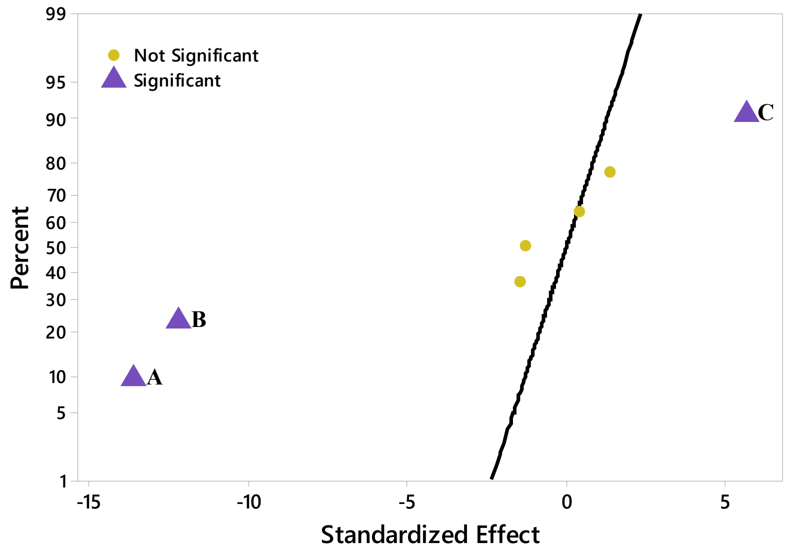

Figure 7. Model validation through standardized effects.

The effectiveness of the model is further increased by considering the residual analysis, and the respective residual plots for both car models are shown in Figures 8 and 9. These plots are considered for the response variable (fuel economy) concerning variations in air conditioner, tire pressure, and traffic patterns. Figures 8a and 9a highlight that the residuals of the proposed models are normally distributed. This normality test is achieved because all the scatter points follow the trendline. Therefore, the deviation between the observed and the estimated values of the model is negligible, which, in turn, enhances the model effectiveness.

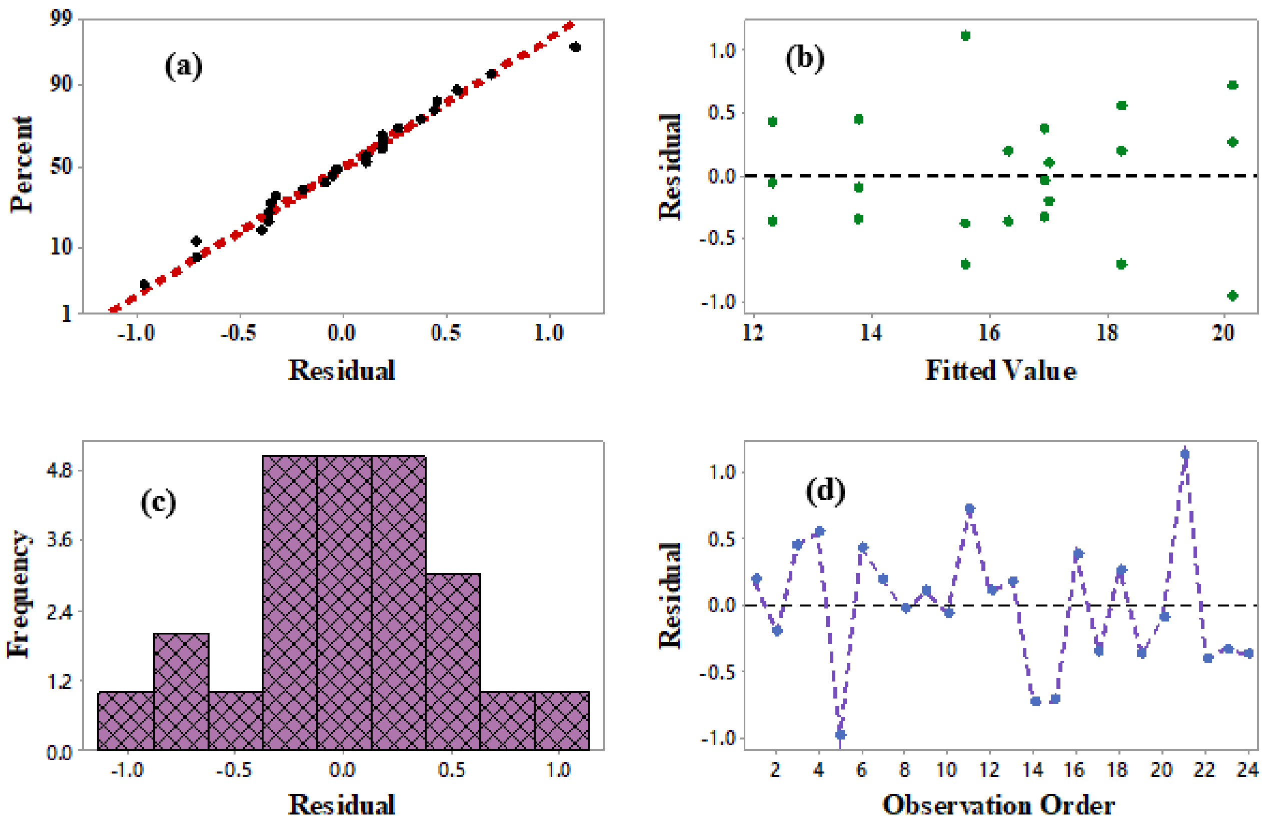

Figure 8. Residual Plots for the Toyota Corolla Model; (**a**) Normal Probability (**b**) versus Fits (**c**) Histogram (**d**) versus Order.

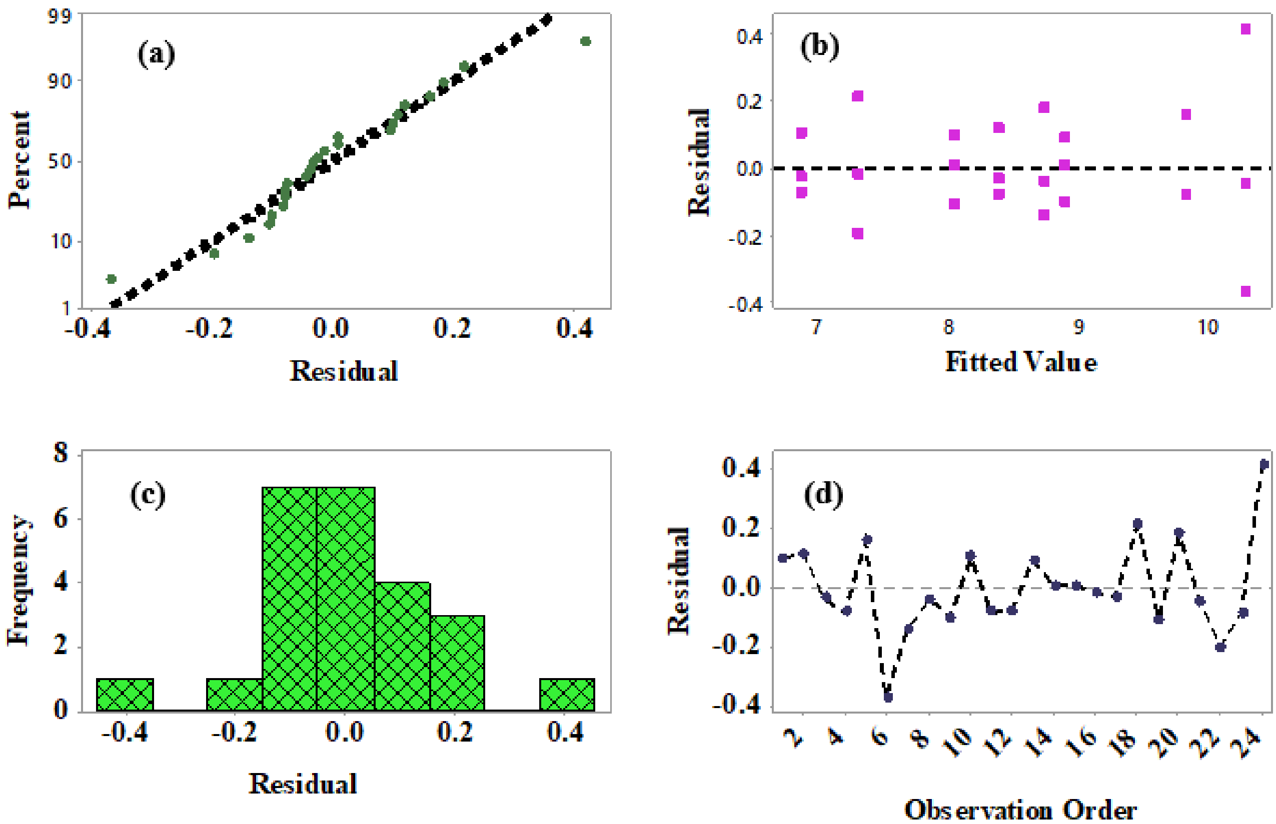

Figure 9. Residual Plots for the GMC Yukon Model; (**a**) Normal Probability (**b**) versus Fits (**c**) Histogram (**d**) versus Order.

Furthermore, Figures 8b and 9b show the statistical trends between the residuals and the fitted values. It is observed that the constant variance premise cannot be rejected because the residuals are equally distributed above and below the reference (Y = 0) line. One of the possible reasons is that the 2^3 factorial design model does not underestimate or overestimate the actual fuel consumption data values, and therefore, the proposed model has created an unbiased effect. Similarly, Figures 8c and 9c highlight the frequency distribution of the residuals, and it is observed that residuals are normally distributed. Finally, Figures 8d and 9d show the random variations of the residuals due to the replication of the fuel economy. Therefore, based on the outcomes of the proposed model, it is recommended to investigate the fuel economy of the vehicle by considering the integration between the controllable input factors.

5. Conclusions

Researchers have been considering multiple optimization algorithms in engineering domains for sustainable world solutions. Furthermore, over the past few years, different statistical techniques have been implied in automobiles for sustainable vehicle routings. Therefore, in this research work, at first, a particular route in Jeddah was selected for the collection of relevant fuel economy data under the different designs of experiments. The factorial analysis was implemented on the gathered data for the Toyota and GMC Yukon car models to establish the statistical interpretations of the fuel economy. The results highlight that the fuel economy is optimal under the low air conditioner temperature, light traffic patterns, and 34 PSI tire pressure. Furthermore, analysis of variance (ANOVA) was carried out to satisfy the outcomes of the factorial design of the experiment. The outcomes highlighted that *p*-values of all the input factors are less than the level of significance, and therefore, the proposed model shows interesting statistical facts for interpolating the vehicle fuel economy. It is also observed that two-way interaction between traffic pattern and tire pressure has the most significant influence on the levels of fuel economy. Therefore, it is recommended to carefully integrate those factors for the economic routings of the vehicles. Furthermore, multivariate regression analysis was carried out to estimate the correlation between the input factors and the response variable of the model. The outcomes highlight that both air conditioner temperature and traffic patterns in Jeddah have a significant negative effect on fuel economy. The model estimator for GMC Yukon has greater value as compared to the Toyota car model, and therefore, random factors adversely affect the GMC Yukon fuel economy. Therefore, the proposed model does not only allow us to investigate the automobile's fuel economy but also enlightens the importance of correlated factors for sustainable economically vehicle routings. Furthermore, the insights of the proposed study highlight that all the statistically significant input factors can also be related to the trends of fuel consumption, and this would be accomplished by multiplying the obtained fuel economy with the distance covered in a specific route. The insight based on the experimental study has a considerable implication for environmental conservation (greenhouse emission), policies, and fuel economy for individual drivers. The conclusion based on the multivariate linear regression analysis depicts that automobile vehicles with heavy engines and large compressors are likely to experience a substantially higher effect on fuel consumption efficiency due to interaction between multiple factors. Additionally, the choice of the pressure per square inch (PSI) range of 28–34 is also likely to explain the fact that variations in tire pressure have a higher significant positive effect on fuel consumption of heavy-engine automobiles. Based on the novel findings, it is highly recommended to utilize the Toyota car model for investigating the influence of random factors (acceleration, braking frequency, metrological conditions, and driver experience) on the fuel economy. Apart from that, the proposed study can be utilized in any transportation routes to interpolate the significance of highly correlated input factors, which, in turn, will provide dynamic trends of fuel economy.

6. Limitations and Future Recommendations

The study relies on the experimental research design to ascertain the key factors that influence vehicle fuel economy. Moreover, the statistical findings are also limited by the external metrological conditions and the reason why it is highly recommended to consider the site-conditions in the developed model for achieving the significant interaction between multiple input variables. Apart from that, based on the outcomes, it is also recommended to consider the response surface methodology for interpreting statistical correlation between the response variable and input factors of the model. Nevertheless, three replications were considered to investigate the correlation and influence of individual input factors on the fuel economy. It is highly recommended to enhance the model accuracy by considering multiple replications with different routes to ascertain the significant interactions between the input factors. The outcomes of the proposed methodology enlighten the significance of highly correlated variables that affect the trends of fuel economy. However, it is also recommended to consider the statistical outcomes in terms of fuel consumption, and this would be achieved by calculating the covered distance in a particular route. Finally, different study settings and car models would help the researchers to increase the validity between observed and measured values of statistically significant factors.

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