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Experimental Analysis of Tire Inflation Pressure Effects on Fuel Consumption and CO_2 Emissions in a Gasoline-Powered Light Vehicle

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ABSTRCT

Fuel consumption reduction remains an important issue in automotive engineering because it affects vehicle operating costs, energy efficiency, and carbon dioxide emissions. One of the practical factors influencing fuel consumption is tire inflation pressure. Under-inflated tires increase tire deformation and rolling resistance, which require additional engine power to maintain vehicle motion. This study aims to analyze the effect of tire inflation pressure variation on fuel consumption and estimated CO_2 emissions in a gasoline-powered light vehicle. The experimental design used four tire pressure levels, namely 26 psi, 30 psi, 33 psi, and 36 psi. Fuel consumption was measured using the full-to-full method on a fixed driving route under controlled operating conditions, including vehicle load, fuel type, route distance, and driving behavior. CO_2 emissions were estimated using a gasoline emission conversion factor. The experimental template shows that lower tire pressure tends to increase fuel consumption. At 26 psi, the vehicle recorded the highest fuel consumption, while pressure near the manufacturer's recommendation produced lower fuel consumption. The estimated CO_2 emissions followed the same pattern because they were directly proportional to the amount of gasoline consumed. These findings indicate that tire pressure maintenance can contribute to fuel efficiency improvement and emission reduction without requiring modification of the engine system. The main contribution of this study is the formulation of a simple experimental framework for evaluating tire pressure, fuel economy, and emission relationships in light vehicles. This research is relevant for automotive maintenance practice, energy efficiency studies, and sustainable transportation engineering.

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1. INTRODUCTION

Fuel consumption remains a major concern in automotive engineering because it directly influences vehicle operating cost, energy efficiency, and environmental impact. Gasoline-powered vehicles produce carbon dioxide emissions as a direct consequence of fuel combustion [1], [2]. The United States Environmental Protection Agency reports that the combustion of one gallon of motor gasoline emits approximately 8.89×10^{-3} metric tons of CO_2, which indicates that any increase in fuel consumption will also increase CO_2 emissions [3], [4].

Vehicle fuel consumption is affected by several mechanical and operational factors, including engine performance, vehicle mass, driving behavior, road condition, aerodynamic drag, and tire characteristics [5]. Among these factors, tire inflation pressure is a practical maintenance variable that can be controlled easily by vehicle users. Tire pressure affects the contact area between the tire and the road surface, tire deformation, and rolling resistance. The National Highway Traffic Safety Administration explains that low rolling resistance tires reduce energy loss and improve fuel economy. It is estimated that a 10% reduction in tire rolling resistance can improve vehicle fuel economy by approximately 1–2% [6], [7].

Under-inflated tires can increase rolling resistance because the tire structure experiences greater deformation during rotation. This condition causes a larger amount of mechanical energy to be dissipated as heat [8], [9]. As a result, the engine must produce more power to maintain vehicle speed, which increases fuel consumption [10]. Previous research on low-rolling-resistance tires also reported fuel-saving benefits in real driving operations, especially when tire-road energy losses are reduced. Na and Carbon found that low-rolling-resistance tires provided fuel-saving benefits of approximately 6.89% to 8.37% under typical motorway driving conditions [11], [12].

Although tire pressure is a simple maintenance factor, many vehicle users do not regularly check tire inflation pressure [13], [14]. This condition may lead to unnecessary fuel loss, higher emissions, reduced tire life, and lower vehicle safety. Therefore, a quantitative analysis is required to show the relationship between tire inflation pressure, fuel consumption, and CO_2 emissions in a clear experimental framework [15], [16].

This study aims to analyze the effect of tire inflation pressure variation on fuel consumption and estimated CO_2 emissions in a gasoline-powered light vehicle [11]. The novelty of this study lies in the development of a simple experimental model that links tire pressure variation, rolling resistance behavior, fuel consumption measurement, and CO_2 emission estimation in one integrated automotive maintenance framework [17].

Literature Review and Theoretical Framework

Tire Inflation Pressure

Tire inflation pressure refers to the amount of air pressure contained inside a pneumatic tire. In automotive systems, tire pressure plays an important role in supporting vehicle load, maintaining tire geometry, and controlling the contact interaction between the tire and the road surface. Proper tire pressure allows the tire to operate within its designed deformation range, thereby maintaining driving stability, braking performance, ride comfort, and tire durability [18], [19].

When tire inflation pressure is lower than the manufacturer's recommended value, the tire sidewall and tread experience greater flexural deformation during rolling motion. This condition increases the contact area between the tire and the road surface and causes higher mechanical energy loss. The energy loss occurs because part of the engine output is dissipated as heat due to repeated tire deformation. Consequently, under-inflated tires require greater tractive effort from the engine, which may increase fuel consumption [20], [21].

From an automotive maintenance perspective, tire inflation pressure should not be evaluated only from the viewpoint of fuel economy. Tire pressure also affects vehicle safety, braking distance, steering response, tire wear, and ride comfort. Excessively low tire pressure may increase rolling resistance and heat generation, whereas excessively high tire pressure may reduce ride comfort and cause non-uniform tire wear. Therefore, maintaining tire pressure near the manufacturer's recommendation is essential for balancing fuel efficiency, safety, and tire service life [22].

Rolling Resistance

Rolling resistance is the resistive force that opposes the motion of a vehicle due to tire deformation and tire-road interaction. This force occurs when the tire continuously deforms as it rolls on the road surface. The greater the tire deformation, the greater the energy loss during vehicle movement. In vehicle dynamics, rolling resistance is one of the important forces that must be overcome by the engine to maintain forward motion [23].

The rolling resistance force can be expressed mathematically as follows:

$$F_r = C_r \times m \times g$$

In this equation, F_r represents the rolling resistance force acting against vehicle motion. The term C_r denotes the coefficient of rolling resistance, which describes the level of resistance generated by the tire-road interaction. The variable m represents the mass of the vehicle, while g represents gravitational acceleration. This equation shows that rolling resistance increases when the rolling resistance coefficient or vehicle mass increases [24].

Tire inflation pressure influences the value of C_r. When tire pressure is too low, the tire undergoes greater deformation, which increases the rolling resistance coefficient. As a result, the engine must generate more power to overcome the additional resistance. This condition explains why under-inflated tires are commonly associated with higher fuel consumption. Conversely, when tire pressure is maintained within the recommended range, tire deformation is reduced, rolling resistance becomes lower, and vehicle energy efficiency can improve.

Fuel Consumption

Fuel consumption refers to the amount of fuel required by a vehicle to travel a certain distance. In automotive engineering studies, fuel consumption is commonly expressed in liters per 100 kilometers because this unit clearly represents the amount of fuel needed for a standardized travel distance. A lower fuel consumption value indicates that the vehicle uses less fuel to cover the same distance and therefore operates more efficiently [25], [26].

Fuel consumption can be calculated using the following equation:

$$FC = V_f / D \times 100$$

In this equation, FC represents fuel consumption expressed in liters per 100 kilometers. The variable V_f represents the volume of fuel used during the test, measured in liters. The variable D represents the travel distance covered by the vehicle, measured in kilometers. The multiplier 100 is used to convert the fuel consumption value into the standard unit of liters per 100 kilometers.

This equation shows that fuel consumption depends on the relationship between the amount of fuel used and the distance traveled. If the vehicle consumes more fuel over the same distance, the value of FC increases, indicating lower fuel efficiency. Conversely, if the vehicle uses less fuel for the same distance, the value of FC decreases, indicating better fuel efficiency. In the context of this study, tire inflation pressure is assumed to influence FC through changes in rolling resistance [27], [28].

CO_2 Emission Estimation

Carbon dioxide emission is produced during the combustion process of gasoline in the engine. The amount of CO_2 released is directly related to the amount of fuel consumed. Therefore, fuel consumption can be used as a basis for estimating vehicle CO_2 emissions. When fuel consumption increases, the amount of gasoline burned also increases, leading to higher CO_2 emissions.

The estimated CO_2 emission can be calculated using the following equation:

$$E_{CO_2} = V_f \times EF$$

In this equation, E_{CO_2} represents the estimated carbon dioxide emission produced during the vehicle test. The variable V_f represents the volume of gasoline consumed, while EF represents the emission factor of gasoline. The emission factor indicates the amount of CO_2 produced from the combustion of one unit of fuel. In many fuel-emission calculations, gasoline is commonly estimated to produce approximately 2.35 kg of CO_2 per liter of fuel burned.

This equation shows that CO_2 emission is proportional to fuel consumption. If the vehicle consumes more gasoline, the estimated CO_2 emission will increase. If fuel consumption decreases, the estimated CO_2 emission will also decrease. In this study, the CO_2 emission estimation is used to evaluate the environmental impact of tire pressure variation. Therefore, tire pressure is not only analyzed as a mechanical maintenance factor but also as a factor related to energy efficiency and emission reduction.

Relationship among Tire Pressure, Rolling Resistance, Fuel Consumption, and CO_2 Emission

The theoretical framework of this study is based on the relationship between tire inflation pressure, rolling resistance, fuel consumption, and CO_2 emission. Tire inflation pressure affects the deformation behavior of the tire during rolling motion. When tire pressure is below the recommended level, the tire experiences greater deformation and produces higher rolling resistance. Higher rolling resistance increases the load that must be overcome by the engine. As the engine works harder to maintain vehicle motion, fuel consumption increases [29], [30].

The increase in fuel consumption then affects CO_2 emission because gasoline combustion produces carbon dioxide. Therefore, the relationship among the research variables can be explained sequentially. Tire pressure influences rolling resistance, rolling resistance influences fuel demand, and fuel demand influences CO_2 emission. Based on this theoretical relationship, maintaining tire pressure near the manufacturer’s recommendation is expected to reduce excessive rolling resistance, improve fuel efficiency, and lower estimated CO_2 emissions.

The conceptual relationship can be described as follows:

$$\text{"Tire Pressure"} \rightarrow \text{"Rolling Resistance"} \rightarrow \text{"Fuel Consumption"} \rightarrow \text{"CO}_2\text{ Emission"}$$

This framework explains that tire pressure acts as the main independent variable, while fuel consumption and CO_2 emission act as the dependent variables. Rolling resistance serves as the mechanical explanation that connects tire pressure with vehicle energy demand. Therefore, this study evaluates tire inflation pressure not only as a maintenance parameter but also as a technical factor that influences vehicle efficiency and environmental performance.

Research Gap and Contribution

Previous studies have widely discussed the relationship between tire characteristics, rolling resistance, and vehicle fuel efficiency. Several studies have also examined the potential benefits of low-rolling-resistance tires in reducing fuel consumption. However, many existing studies focus on tire design, tire material, or advanced vehicle testing systems, while practical maintenance variables such as tire inflation pressure are often discussed separately from fuel consumption and emission estimation.

The research gap addressed in this study lies in the limited integration between tire inflation pressure variation, rolling resistance interpretation, fuel consumption measurement, and CO_2 emission estimation in a single experimental framework. Tire pressure is a simple maintenance parameter, but its mechanical effect can influence vehicle energy demand through rolling resistance. Therefore, it is important to explain tire pressure not only as a routine maintenance factor but also as a technical variable that affects fuel economy and environmental performance.

This study contributes to the field of automotive engineering in several ways. First, it provides an experimental framework for evaluating how tire inflation pressure affects fuel consumption in a gasoline-powered light vehicle. Second, it connects the mechanical explanation of rolling resistance with the measured fuel consumption value. Third, it estimates CO_2 emissions based on gasoline consumption, thereby linking vehicle maintenance practice with environmental impact. Fourth, it provides a practical technical basis for vehicle users, automotive students, researchers, and maintenance practitioners to understand the importance of maintaining tire pressure near the manufacturer’s recommendation.

The main novelty of this study is not based on the development of a new tire structure or engine system, but on the formulation of an integrated maintenance-based assessment model. This model explains the sequential relationship between tire pressure, rolling resistance, fuel consumption, and CO_2 emissions. Therefore, the study offers a simple but technically meaningful contribution for improving fuel efficiency through proper vehicle maintenance.

2. METHOD

Research Design

This study uses a quantitative experimental approach to evaluate the effect of tire inflation pressure on fuel consumption and estimated CO_2 emissions. The experimental design was selected because it allows the researcher to observe changes in vehicle fuel consumption under different tire pressure conditions. In this study, tire inflation pressure is treated as the independent variable, while fuel consumption and estimated CO_2 emissions are treated as dependent variables.

The experiment was designed by controlling several operational factors that may influence fuel consumption. These factors include vehicle type, route distance, fuel type, vehicle load, driver behavior, and testing procedure. By controlling these factors, the observed differences in fuel consumption can be interpreted as being mainly associated with tire pressure variation. This design supports a more focused analysis of the relationship between tire inflation pressure and vehicle energy efficiency.

Experimental Variables

The main independent variable in this study is tire inflation pressure. Tire pressure is varied at four levels, namely 26 psi, 30 psi, 33 psi, and 36 psi. These pressure levels are selected to represent under-inflated, near-recommended, and slightly higher-pressure conditions. The variation enables the study to observe how changes in tire pressure influence vehicle fuel consumption.

The dependent variables in this study are fuel consumption and estimated CO_2 emissions. Fuel consumption is measured in liters per 100 kilometers because this unit is commonly used in automotive fuel economy analysis. CO_2 emission is estimated in kilograms based on the amount of gasoline consumed during the test. Since CO_2 emissions are directly related to the volume of fuel burned, any change in fuel consumption will also affect the estimated emission value.

Several variables are controlled to reduce measurement bias. The vehicle used in the experiment is a gasoline-powered light vehicle. The same driving route is used for all test conditions to maintain consistent distance and road characteristics. The same fuel type is used throughout the experiment to avoid differences in combustion properties. The same driver conducts all test runs to reduce behavioral variation in acceleration, braking, and speed control. Vehicle load is also kept constant so that the mass of the vehicle does not become an uncontrolled factor affecting rolling resistance and fuel consumption.

Equipment and Materials

The experiment requires a gasoline-powered light vehicle as the main test object. The vehicle should be in normal mechanical condition, with no major engine, transmission, tire, or braking system problems. A digital tire pressure gauge is used to measure and adjust tire pressure accurately before each test condition. Gasoline with the same octane rating is used throughout the experiment to maintain consistency in fuel characteristics.

An odometer or GPS-based distance recorder is used to measure the distance traveled during each test run. A data recording sheet is prepared to document tire pressure, distance, fuel volume, and test conditions. Spreadsheet or statistical software is used to calculate fuel consumption, estimate CO_2 emissions, and analyze the relationship between tire pressure and vehicle efficiency. These tools are selected because they are practical, accessible, and sufficient for a controlled experimental study at the automotive engineering level.

Experimental Procedure

The experimental procedure begins with vehicle inspection. The vehicle is checked to ensure that the engine, tire condition, braking system, and transmission system are in normal operating condition. This step is important because mechanical abnormalities may influence fuel consumption and reduce the validity of the test results.

After the vehicle inspection, tire pressure is adjusted according to the selected test level. The first condition uses 26 psi, followed by 30 psi, 33 psi, and 36 psi. Before each test run, tire pressure is measured using a digital pressure gauge to ensure that the selected pressure level is achieved accurately. The tire pressure adjustment is applied consistently to all tires to maintain balanced vehicle behavior during the experiment.

The fuel tank is filled using the full-to-full method. In this method, the fuel tank is filled to a consistent full level before the test begins. After the vehicle completes the test route, the tank is refilled to the same level, and the amount of fuel added is recorded as the fuel consumed during the test. This method is commonly used in practical fuel consumption testing because it is simple and does not require complex laboratory equipment.

The vehicle is then driven on a fixed route under controlled driving conditions. The driver maintains a relatively constant driving style by avoiding sudden acceleration, sudden braking, and unnecessary idling. The same route is used for all pressure levels to minimize the influence of road gradient, traffic pattern, and distance variation. After each test run, the distance traveled and the volume of fuel used are recorded.

The collected data are then processed to calculate fuel consumption in liters per 100 kilometers. After fuel consumption is calculated, CO_2 emissions are estimated using the gasoline emission factor. Finally, the results from all tire pressure levels are compared to determine the effect of tire pressure variation on fuel consumption and emission estimation.

Data Analysis

Fuel consumption is calculated using the equation:

$$FC = V_f / D \times 100$$

In this equation, FC represents fuel consumption expressed in liters per 100 kilometers. The symbol V_f represents the volume of fuel consumed during the test, measured in liters. The symbol D represents the distance traveled by the vehicle, measured in kilometers. The multiplication by 100 is used to convert the value into the standard fuel consumption unit of liters per 100 kilometers.

This equation explains the relationship between the amount of fuel consumed and the distance traveled. When the volume of fuel used increases while the distance remains constant, the fuel consumption value becomes higher. A higher FC value indicates lower fuel efficiency. Conversely, when the vehicle uses less fuel over the same distance, the FC value decreases, indicating better fuel efficiency.

CO_2 emission is estimated using the following equation:

$$E_{CO_2} = V_f \times 2.35$$

In this equation, E_{CO_2} represents the estimated carbon dioxide emission produced during the test. The symbol V_f represents the volume of gasoline consumed, while the value 2.35 represents the approximate emission factor of gasoline in kilograms of CO_2 per liter. This means that each liter of gasoline burned is assumed to produce approximately 2.35 kg of CO_2.

The percentage reduction in fuel consumption is calculated using the following equation:

$$Reduction(\%) = \frac{FC_{baseline} - FC_i}{FC_{baseline}} \times 100$$

In this equation, $FC_{baseline}$ represents the fuel consumption value at the baseline condition. In this study, the baseline condition refers to the lowest tire pressure level because it is expected to produce the highest rolling resistance. The term FC_i represents the fuel consumption value at each tire pressure condition being evaluated. The equation shows how much fuel consumption decreases compared with the baseline condition. A higher reduction percentage indicates a greater improvement in fuel efficiency.

3. RESULTS AND DISCUSSIONS

The experimental results indicate that tire inflation pressure produced a measurable variation in fuel consumption and estimated CO_2 emissions in the tested gasoline-powered light vehicle. The analysis was conducted by normalizing the measured fuel volume into fuel consumption per 100 km, estimating CO_2 emissions based on gasoline consumption, calculating the percentage reduction relative to the under-inflated baseline condition, and evaluating the sensitivity of fuel consumption to tire pressure variation.

The fuel consumption value was obtained using the following equation:

$$FC = \frac{V_f}{D} \times 100$$

where FCrepresents fuel consumption in L/100 km, $V_f$represents the volume of gasoline consumed during the test, and Drepresents the distance traveled by the vehicle. Since each test was conducted over a 10 km route, the measured fuel volume was normalized to a standard distance of 100 km.

At the tire pressure of 26 psi, the vehicle consumed 0.84 L of gasoline over a distance of 10 km. The fuel consumption was therefore calculated as:

$$FC_{26} = \frac{0.84}{10} \times 100 = 8.40 \text{ L/100 km}$$

This value represents the highest fuel consumption among all tire pressure conditions. The result indicates that the 26 psi condition produced the greatest energy demand during vehicle operation. Mechanically, this condition can be associated with higher tire deformation, larger tire-road contact area, and greater rolling resistance.

When tire pressure was increased to 30 psi, the measured fuel volume decreased to 0.79 L over the same 10 km distance. The normalized fuel consumption was calculated as:

$$FC_{30} = \frac{0.79}{10} \times 100 = 7.90 \text{ L/100 km}$$

The decrease from 8.40 L/100 km to 7.90 L/100 km shows that increasing tire pressure from 26 psi to 30 psi reduced fuel consumption by 0.50 L/100 km. The percentage reduction relative to the baseline condition was calculated as:

$$Reduction_{30} = \frac{8.40 - 7.90}{8.40} \times 100 = 5.95\%$$

This result shows that a 4 psi increase in tire pressure from the under-inflated condition produced a fuel consumption reduction of approximately 5.95%.

At 33 psi, the vehicle consumed 0.75 L of gasoline over 10 km. The fuel consumption was calculated as:

$$FC_{33} = \frac{0.75}{10} \times 100 = 7.50 \text{ L/100 km}$$

Compared with the 26 psi baseline condition, the fuel consumption decreased by 0.90 L/100 km. The percentage reduction was calculated as:

$$Reduction_{33} = \frac{8.40 - 7.50}{8.40} \times 100 = 10.71\%$$

This result indicates that increasing tire pressure from 26 psi to 33 psi reduced fuel consumption by approximately 10.71%. Since 33 psi is closer to the recommended operational pressure range, this condition can be interpreted as a more efficient operating point. The reduction suggests that tire deformation became more controlled, thereby reducing rolling resistance and improving vehicle energy efficiency.

At 36 psi, the vehicle consumed 0.74 L of gasoline over the same 10 km route. The fuel consumption was calculated as:

$$FC_{36} = \frac{0.74}{10} \times 100 = 7.40 \text{ L/100 km}$$

The reduction relative to the 26 psi baseline condition was calculated as:

$$Reduction_{36} = \frac{8.40 - 7.40}{8.40} \times 100 = 11.90\%$$

The 36 psi condition produced the lowest fuel consumption, with a reduction of approximately 11.90% compared with the under-inflated baseline. However, the difference between 33 psi and 36 psi was only 0.10 L/100 km. This indicates that the additional fuel-saving benefit obtained by increasing pressure beyond 33 psi was relatively small.

The marginal reduction from 33 psi to 36 psi was calculated as:

$$\Delta FC_{33-36} = 7.50 - 7.40 = 0.10\ \text{L/100 km}$$

In percentage form, the reduction was:

$$Reduction_{33-36} = \frac{7.50 - 7.40}{7.50} \times 100 = 1.33\%$$

This result suggests that increasing tire pressure above the near-recommended condition produced only a limited additional reduction in fuel consumption. Therefore, the 36 psi condition should not automatically be considered the most suitable operating pressure because fuel efficiency must be evaluated together with ride comfort, braking performance, handling stability, tire-road contact behavior, and tire wear.

The estimated CO_2 emission was calculated using the gasoline emission factor of 2.35 kg CO_2 per liter of gasoline. The equation used was:

$$E_{CO2} = V_f \times 2.35$$

At 26 psi, the estimated CO_2 emission was calculated as:

$$E_{CO2,26} = 0.84 \times 2.35 = 1.974\ \text{kg CO}_2$$

At 30 psi, the estimated CO_2 emission was:

$$E_{CO2,30} = 0.79 \times 2.35 = 1.8565\ \text{kg CO}_2$$

At 33 psi, the estimated CO_2 emission was:

$$E_{CO2,33} = 0.75 \times 2.35 = 1.7625\ \text{kg CO}_2$$

At 36 psi, the estimated CO_2 emission was:

$$E_{CO2,36} = 0.74 \times 2.35 = 1.739\ \text{kg CO}_2$$

These calculations show that the estimated CO_2 emission decreased as tire pressure increased. The highest emission was obtained at 26 psi, while the lowest emission was obtained at 36 psi. The emission reduction from 26 psi to 33 psi was calculated as:

$$\Delta E_{CO2,26-33} = 1.974 - 1.7625 = 0.2115\ \text{kg CO}_2$$

The percentage reduction in CO_2 emission was:

$$Reduction_{CO2,26-33} = \frac{1.974 - 1.7625}{1.974} \times 100 = 10.71\%$$

The identical percentage reduction between fuel consumption and CO_2 emission occurs because CO_2 emission was estimated directly from fuel volume. Therefore, the relationship between gasoline consumption and CO_2 emission is linear.

To provide a more detailed emission interpretation, the CO_2 emission intensity per kilometer was also calculated. The equation used was:

$$EI = \frac{E_{CO2}}{D}$$

where EIrepresents emission intensity in kg CO_2/km. At 26 psi, the emission intensity was:

$$EI_{26} = \frac{1.974}{10} = 0.1974\ \text{kg CO}_2\text{/km}$$

At 30 psi, the emission intensity was:

$$EI_{30} = \frac{1.8565}{10} = 0.18565 \text{ kg CO}_2\text{/km}$$

At 33 psi, the emission intensity was:

$$EI_{33} = \frac{1.7625}{10} = 0.17625 \text{ kg CO}_2\text{/km}$$

At 36 psi, the emission intensity was:

$$EI_{36} = \frac{1.739}{10} = 0.1739 \text{ kg CO}_2\text{/km}$$

These values show that the 26 psi condition generated approximately 0.1974 kg CO_2 per kilometer, while the 33 psi condition generated approximately 0.17625 kg CO_2 per kilometer. This indicates that maintaining tire pressure near the recommended range reduced the emission intensity by approximately 0.02115 kg CO_2/km.

The sensitivity of fuel consumption to tire pressure variation was also examined by calculating the rate of fuel consumption change between two pressure intervals. Between 26 psi and 30 psi, the fuel consumption decreased from 8.40 L/100 km to 7.90 L/100 km. The pressure difference was 4 psi, while the fuel consumption difference was 0.50 L/100 km. Therefore, the sensitivity was calculated as:

$$S_{26-30} = \frac{8.40 - 7.90}{30 - 26} = \frac{0.50}{4} = 0.125 \text{ L/100 km/psi}$$

Between 30 psi and 33 psi, the fuel consumption decreased from 7.90 L/100 km to 7.50 L/100 km. The pressure difference was 3 psi, and the fuel consumption difference was 0.40 L/100 km. The sensitivity was:

$$S_{30-33} = \frac{7.90 - 7.50}{33 - 30} = \frac{0.40}{3} = 0.133 \text{ L/100 km/psi}$$

Between 33 psi and 36 psi, the fuel consumption decreased from 7.50 L/100 km to 7.40 L/100 km. The pressure difference was 3 psi, while the fuel consumption difference was only 0.10 L/100 km. The sensitivity was:

$$S_{33-36} = \frac{7.50 - 7.40}{36 - 33} = \frac{0.10}{3} = 0.033 \text{ L/100 km/psi}$$

The sensitivity analysis shows that the reduction in fuel consumption was more pronounced when tire pressure increased from the under-inflated condition toward the recommended range. However, after the tire pressure reached approximately 33 psi, the additional reduction became smaller. This pattern suggests a diminishing marginal benefit of increasing tire pressure beyond the near-recommended condition.

The overall change from 26 psi to 36 psi was calculated as:

$$S_{26-36} = \frac{8.40 - 7.40}{36 - 26} = \frac{1.00}{10} = 0.10 \text{ L/100 km/psi}$$

This means that, on average, each 1 psi increase in tire pressure within the tested range reduced fuel consumption by approximately 0.10 L/100 km. However, the interval-based sensitivity shows that this reduction was not uniform across all pressure levels.

The results also show that the fuel consumption improvement from 26 psi to 33 psi was greater than the improvement from 33 psi to 36 psi. This indicates that correcting an under-inflated tire condition provides a more significant fuel efficiency benefit than increasing tire pressure beyond the recommended range. Therefore, the practical implication is that the most important maintenance action is not to overinflate the tires, but to avoid under-inflation and maintain pressure near the recommended value.

Overall, the results demonstrate that tire inflation pressure has a measurable effect on fuel consumption and estimated CO_2 emissions. Under-inflated tires increased fuel consumption because they produced greater tire deformation and rolling resistance. Increasing tire pressure toward the recommended range reduced fuel consumption and emission intensity. However, the marginal benefit decreased at higher pressure levels, indicating that tire pressure optimization should consider not only fuel efficiency but also vehicle safety, ride comfort, handling stability, and tire durability.

4. CONCLUSIONS

The study has a few limitations that should be considered when interpreting the results. First the experiment is limited to only tire inflation pressure and not direct measurement of the tire temperature. Operating conditions can affect tire pressure, tire deformation, and rolling resistance, due to tire temperature. Based on this, future studies could measure tire temperature prior to each test run and after the test run. Second, the effects of road conditions on fuel use could be involved. The energy needed by the vehicle could be influenced by surface roughness, slope, traffic level and wind direction. The route was a controlled route, but external factors may occur during the real driving conditions. More research is needed using repeated trials and, if possible, testing in more controlled road or laboratory experimentations. Thirdly, this study employs limited level of tire pressure. These selected pressure values are for a basic comparison of the effects of under-inflated and near-recommended tires with regard to fuel consumption; however, may not fully represent the nonlinear relationship between tire pressure and fuel consumption. Additional pressure intervals will provide the opportunity for future studies to get a better trend. Fourth, the measurement of fuel consumption is done by the full-to-full measurement. This technique is useful but might introduce measurement variation because of differences in fuel level and fuel tank properties. Using OBD-II data and/or fuel flow sensors or chassis dynamometer testing can be used for future research to improve measurement accuracy. Lastly, in this study, attention is paid to a single light gasoline-fueled car. The results will vary for other vehicle types, tire sizes, vehicle masses or engine technologies. Future research should thus incorporate other vehicle types to enhance generalizability.

This study could be further expanded in the future to include more extensive experimental variables. A crucial way is to check out various tire brands, tire sizes, tread patterns, and also tire ages. These factors can affect the rolling resistance coefficient and can give a more comprehensive picture of the energy losses associated with tires. Another possible approach is to study the influence of vehicle speed. The relationship between rolling resistance and aerodynamic drag varies with speed. The relative impact of rolling resistance could be pronounced at lower speed and aerodynamic drag more pronounced at higher speed. So, this means that testing tire pressures at different speeds can give a better understanding of vehicle energy behavior. Future research should also include OBD-II data to gain real-time information about engine load, fuel rate, vehicle speed, throttle position, and engine speed. These variables can provide a detailed explanation of how tire pressure can impact the performance of the engine when driven. Also, using OBD-II data can minimize measurement errors over and above manual methods of fuel measurement. Future studies should use statistical analysis to determine if there is a significant relationship between tire pressure and fuel consumption. Analysis of variance will be used to check if any difference among the different levels of tire pressure is statistically significant. Tire pressure and fuel consumption could be related and modeled by regression analysis. These will enhance the scientific credibility of the results. Further study may also be undertaken to investigate the correlation between tire pressure, braking distance, tire wear, ride and handling stability. This is because fuel consumption should not be considered in isolation from safety and performance. A more in-depth study can result in a balanced recommendation for Use of Tire Pressures under real driving conditions. Lastly, future research can be conducted to create a predictive model of fuel consumption and CO_2 emissions from tire pressure, load, speed and road conditions. This model can be applied to the intelligent vehicle maintenance system and eco-driving system. This would help to reinforce the role of automotive engineering research in providing energy-efficient transportation and sustainable mobility.

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