

A Study on Vehicle Tire Inflation and Fuel Consumption

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Executive Summary

This white paper reports on an empirical case study carried out to examine the impact of tire pressure on vehicle fuel consumption. A case study with data obtained from Booster Fuels showed weak collinearity between tire pressure levels and the amount of fuel consumed by vehicles. The data comprised the make/model, license plate number, wheel tire pressure, fuel pumped-in, and the VIN for 30 vehicles for 2019, with information on at least two instances of tire pressure readings and fuel pumped-in.

An 'instance' was defined when both the fuel pumped-in and tire inflation were performed during one service event. The percentage of fuel filled-in and the percentage drop in tire pressures compared to the recommended pressures were calculated for each service event. A regression analysis between the percentage change in tire pressures and the fuel-filled percentage revealed a weak correlation. The Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm was used to minimize the effect of outliers on the correlation observed.

The data collected from Booster Fuels showed a very weak increasing trend when analyzed for collinearity between tire pressures and vehicles' fuel consumption, signifying that low tire pressures can potentially cause an increase in fuel consumption. The weak collinearity is thought to be the consequence of insufficient data points used in the analysis. More data is needed to strengthen the linear relationship between the tire pressures and fuel consumption of a vehicle, which has been well-established in several other empirical studies reviewed and summarized in this white paper.

Introduction

In recent years, there has been a steady rise in fuel consumed by vehicles in California (Stillwater Associates, 2020). Several factors contributing to this fuel demand can be attributed to an increase in vehicle miles traveled (VMT) in the State. Although an increase in VMT directly leads to an increase in fuel consumption (Lin and Prince, 2009), under-inflated tires can play a significant role in the operational performance and efficiency of a vehicle itself, thereby causing an increase in fuel consumption and demand (Grugett et al., 1981). This is corroborated by some recent studies that have established a direct relationship between tire pressures and a vehicle's fuel consumption patterns (Thiriet et al., 2017; Sanchez et al., 2017). This research summarizes that relationship through a literature review. In this white paper, an empirical case study is also carried out to examine the impact of tire pressure on a vehicle's fuel consumption. Data obtained from Booster Fuels have been used for this purpose.

Booster Fuels develops an application-based service to deliver and pump gas in office parking lots. The San Mateo, California based startup partners with campus-based companies, commercial real estate owners, universities, and commercial fleets. It takes nearly a century old supply chain so that every gas station becomes a community park. Fuel Booster uses the latest technology to deliver good old-fashioned personal service In every boost.

Literature Review

Tire pressure plays a critical role in a vehicle's fuel consumption and mobility. For example, the California Energy Commission (CEC) put out a report in 2003 detailing their findings: namely, a correlation between a vehicle's fuel economy and rolling resistance (Calwell et al., 2003). The tires of a moving vehicle cause a slight deformation of the road, creating a rolling resistance that needs to be overcome. The process requires increased use of the automobile's energy and increased fuel consumption. A low tire pressure requires the vehicle to overcome larger rolling resistances. The study conducted by the CEC used a test methodology recommended by tire industry experts. The testing method adopted is the standard for 85% of original equipment manufacturers and over 50% of replacement tire markets. In practice, auto manufacturers strongly support this method that involves determining fuel economy and rolling resistance correlations. The relationship between tire pressure and vehicle efficiency is explicitly endorsed by the Society of Automotive Engineers (SAE) to meet the United States Environmental Protection Agency's (EPA's) road load and speed-dependent fuel consumption tests. In the CEC's study, correlations on fuel economy and rolling resistance came from developing a tire database that consisted of data from tire manufacturers. Specifically, the study found a 2% effect on fuel economy for every 10% change in rolling resistance for highway driving. A 1% effect on fuel economy for every 10% change in rolling resistance was noted for urban driving. These effects vary with vehicle speed and conditions. In that report, the Rubber Manufacturers' Association's findings also noted that when a tire is under-inflated by one pound per square inch (psi), its rolling resistance is increased by approximately 1.1%.

Another program of research by the Committee for the National Tire Efficiency Study in 2006 reported on the relationship between fuel consumption and rolling resistance, which impacts tire wear life (TRB, 2006). Conclusions were based on literature and available data on passenger tire characteristics. Several tire-related operating variables such as vehicle load, inflation pressure, and temperature were found to be critical variables that impact rolling resistance.

The investigations into inflation pressure determined that the relationship between inflation pressure and rolling resistance is not linear. For tires inflated to pressures between 24 and 36 psi, each one-psi drop led to a 1.4% increase in rolling resistance, with more significant rolling resistance effects for changes below 24 psi. The increase in rolling resistance further signifies an increase in fuel consumption.

A study by Baglione et al. (2007) presented the development and application of a vehicle energy analysis methodology to identify vehicle subsystem energy supply and demand. This analysis used various types of information such as empirical chassis dynamometer drive cycle data, vehicle information, measurements from component performance and efficiency data, and fundamental physics and thermodynamics equations, which can account for the energy demand and parasitic losses over thirty vehicle subsystems. Focusing on rolling resistances, and understanding that

rolling resistances come from many factors, researchers narrowed down a single equation that would account for inflation pressure, tire load, and vehicle speed. The analysis for a full-size pick-up truck and 5-speed automatic transmission showed that only 24.6% of the energy satisfies vehicle system demand, and the remaining 75.4% is used to overcome engine inefficiencies. Of the 24.6% in urban drive cycles, rolling resistances take up 15.5% of the energy demand.

Thomas et al. (2014) attempted to quantify the fuel economy effects of three vehicles with accessories or alterations such as open rooftop, mounting cargo box, installing boom for real time anemometry readings in front of the vehicle etc. The three vehicles used were a 2009 Ford Explorer, a 2009 Toyota Corolla, and a 2009 Honda Odyssey Minivans. For the low tire pressure testing, conducted with an SAE standard, up to 10% fuel economy penalties were observed, which indicated that low tire pressures increase fuel consumption.

Guillou and Bradley performed an outdoor test with two identical vehicles and another test with simulations (Guillou and Bradley, 2010). In their comparison of the two test methods, fuel savings predictions using the vehicles and the empirical laws tested in the simulation were consistent in suggesting that an increase in fuel consumption results from an increase in rolling resistance.

D'Ambrosio and Vitolo (2018) performed a computer simulation to show that low tire pressures cause increased rolling resistance, leading to a rise in the energy the vehicle needs to overcome the resistance. The study performed simulations with the standard tire pressure maintained as the baseline and variable pressures investigated. Simulations were run with three strategies for inflation pressures (namely, adaptation to a vertical load, variation during tire warm-up and adjustment according to the average speed) to reduce rolling resistance and keep a car at standard tire pressures. Results showed that fuel consumption could be reduced by up to 2% in highway driving with the adopted strategies.

A study by Pearce and Hanlon (2007) suggested that if car-care facilities were to systematically offer tire pressure checks, along with oil changes, vehicle safety would be increased by decreasing all crashes, saving over a hundred lives per year in the United States. In terms of fuel economy, it would reduce petroleum consumption by over a billion gallons a year. That study aims to reduce fuel consumption and improve fuel economy for the future.

A recent study by Synak and Kalasova reaffirmed that the rate of change in the rolling resistance depends on tire pressure, which ultimately impacts fuel consumption (Synak and Kalasova, 2020). Their research used the vehicle Škoda Fabia 1.9 TDi, 66 kW, engine code AGR, and the tires Continental Winter Contact TS 860 with a size of 195/65 R15 91 T. The research objective was accomplished by measuring the force needed for a vehicle to be towed with specific tire pressures. The findings showed the significance of using and maintaining the correct tire pressure to prevent the engine from consuming increased fuel to overcome the rolling resistance. Additional research findings showed an increase in emissions as a result of the increase in fuel consumption.

Methodology

In this research, a hypothesis can be proposed: that under-inflated tires increase the fuel consumption of vehicles. Therefore, to simplify the analysis, the concept of an 'instance' can

be used. An instance is defined when both the fuel pumped-in and tire inflation were performed during one service event. Thus, a minimum of two consecutive instances would be needed to form a 'before' (instance 1) and 'after' (instance 2) analysis. For each instance, one must calculate the percentage of fuel filled-in and percentage drop in tire pressures below the recommended pressures. Measuring the percentage change would ensure that inflated air and fuel filled-in are normalized across varying vehicle types, recommended tire pressures, and fuel tank capacities.

A regression analysis between the percentage change in tire pressures and the percentage of fuel filled-in will yield the correlation, if there is one. However, the presence of outliers (noise) could affect the results. Subsequently, to minimize the impact of outliers in the analysis, a popular clustering method called Density-Based Spatial Clustering of Applications with Noise (DBSCAN) can be used. DBSCAN is useful in identifying points (noise) that do not belong to a cluster. The details of the DBSCAN algorithm can be found in Ester et al. (1996).

In the next section, the application of the methodology is demonstrated using a case study with actual datasets obtained from Booster Fuels on fuel consumption and tire pressure for vehicles.

Case Study

Booster Fuels, as a gas delivery service company, performs complimentary tire inflation services for its customers. The services reduce car trips to gas stations, which is beneficial to both the motorists (e.g., reducing gas and trip cost) and the environment (e.g., reducing emissions as well as decreasing traffic congestion and parking infrastructure demand) (Booster Fuels, 2020).

Data collected from Booster Fuels were used to evaluate the impact of tire inflation on fuel consumption by vehicle. The data included make/model, license plate number, wheel tire pressure (left rear, left front, right rear, and right front), and VIN for approximately 300 vehicles for the year 2019. Data cleaning resulted in a compilation of 30 vehicles which the history of data collection is available. The amount of gasoline filled-in and corresponding tire pressure changes were available for analysis for these vehicles. The data for the 30 vehicles is presented in Table 1.

Table 1. Data Records on Fuel Filled-in and Tire Pressures for Two (or more) Consecutive Instances

Vehicle	Record of Both Fuel Pumped-In and Tires Inflated (2019)					
	1	2	3	4	5	6
Vehicle 1	Apr 30	May 14				
Vehicle 2	Sept 11	Oct 9				
Vehicle 3	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 4	Sept 11	Oct 9				
Vehicle 5	Sept 11	Oct 9				
Vehicle 6	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 7	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 8	Sept 11	Oct 9				
Vehicle 9	Sept 11	Oct 9				
Vehicle 10	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 11	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 12	Mar 19	Apr 2	Apr 30	May 14	Sept 11	Oct 9
Vehicle 13	Mar 19	Apr 2	Apr 30	May 14	Sept 11	Oct 9
Vehicle 14	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 15	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 16	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 17	Sept 11	Oct 9				
Vehicle 18	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 19	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 20	Mar 19	Apr 2	Apr 30	May 14	Sept 11	Oct 9
Vehicle 21	Sept 11	Oct 9				
Vehicle 22	Apr 30	May 14				
Vehicle 23	Sept 11	Oct 9				
Vehicle 24	Sept 11	Oct 9				
Vehicle 25	Sept 11	Oct 9				
Vehicle 26	Sept 11	Oct 9				
Vehicle 27	Sept 11	Oct 9				
Vehicle 28	Apr 2	Apr 30	May 14			
Vehicle 29	Mar 19	Apr 2	Apr 30	May 14		
Vehicle 30	Apr 2	Apr 30	May 14	Sept 11	Oct 9	

The work's hypothesis would be correct if lower tire pressures (relative to recommended pressures) increased the fuel pumped into the vehicles. For a given instance (a cell in Table 1), the authors calculated the percentage drop in tire pressures in each of the vehicle's four wheels below the recommended pressures. Sixty-eight such data points were obtained and plotted, as shown in the chart of Figure 1.

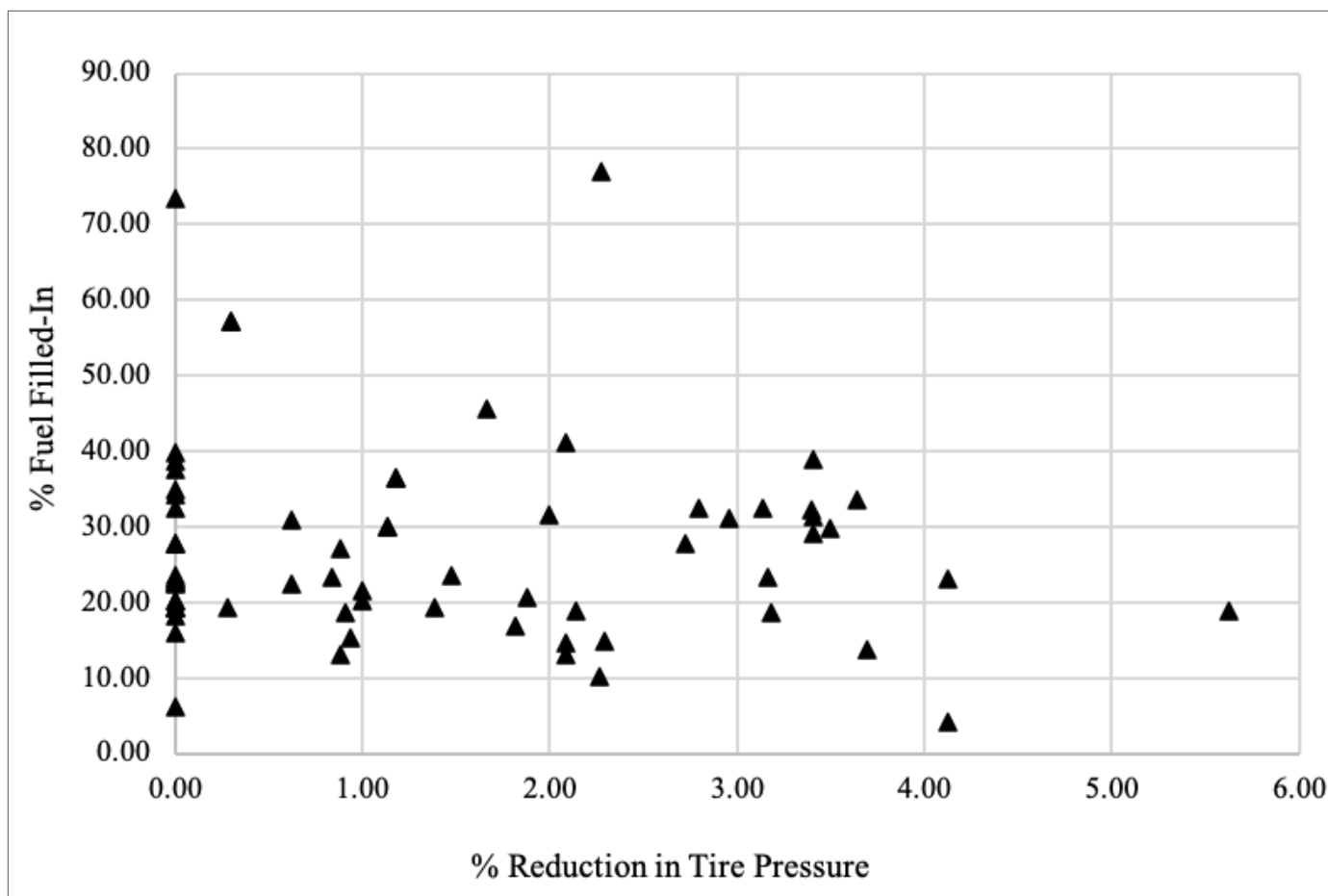


Figure 1. Plot of Percentage Reduction in Tire Pressure vs. Percentage Fuel Filled-In

Results

Linear regression produced an increasing trend between the percentage reduction in tire pressure and the percentage of fuel filled-in to the vehicles. However, the linear regression trendline shows a very weak increasing trend, as evident from the goodness-of-fit measure R^2 value, which is close to 0 (shown in Figure 2). One of the reasons for this weak collinearity could be the insufficient number of data points used in the analysis. There is a possibility of a high value of R^2 if a greater number of inflation and fuel data points are used in the study.

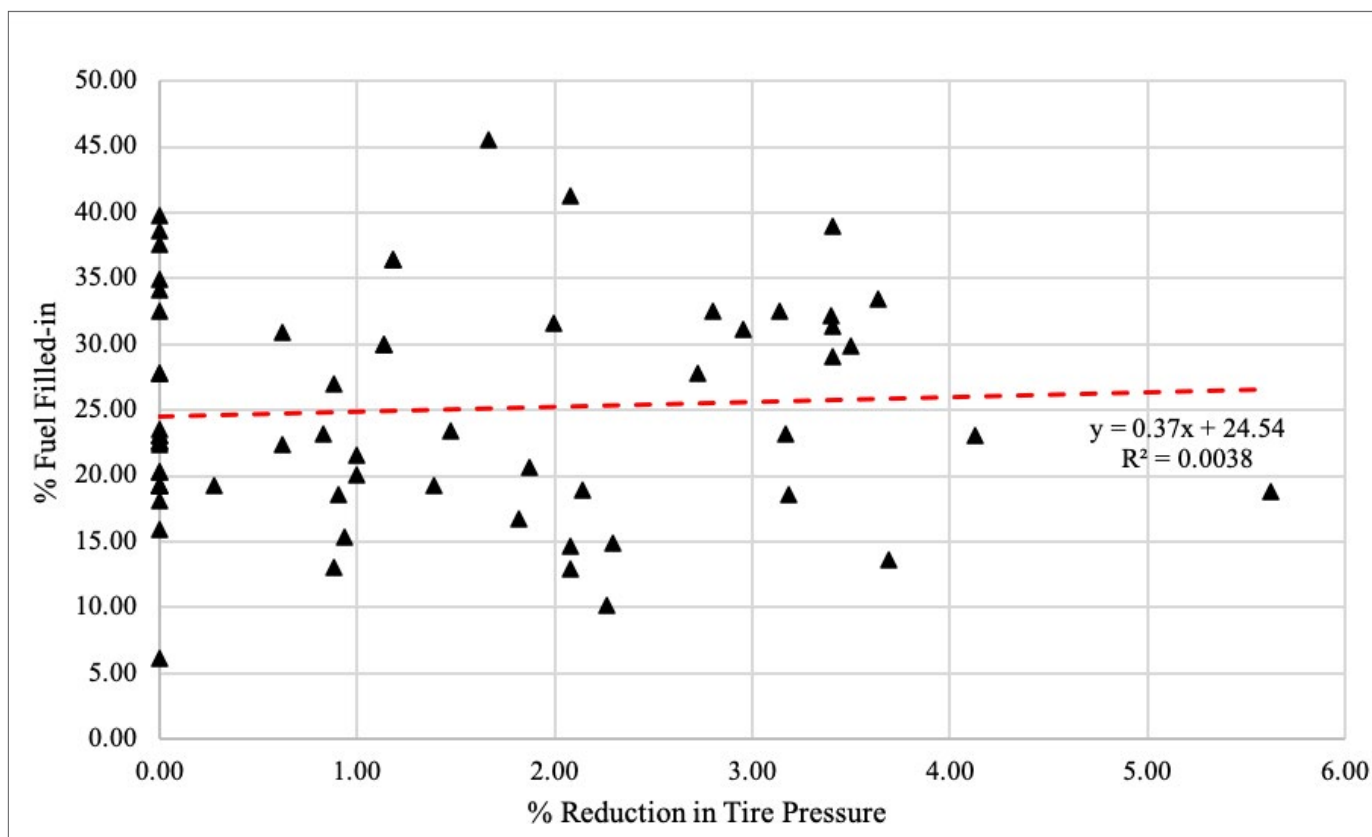


Figure 2. Plot of Percentage Reduction in Tire Pressure vs. Percentage Fuel Filled-In After Eliminating Outliers

Conclusions

Prior literature shows that low tire pressures increase the fuel consumption of a vehicle. In the present research, a case study with data obtained from Booster Fuels showed weak collinearity between tire pressure levels and the amount of fuel consumed by vehicles. It is expected that research conducted with more data will further strengthen this linear relationship between the two variables.

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