

Enhancing Fuel Economy of Automobiles through Design of Experiments

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Figure 1: Experimental setup.



Figure 2 : A typical experimental trial in progress

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Exclusive Summary

As the economy grows, transportation activity too grows in leaps and bounds. Consequently, the demand for fuel efficient automobiles has become essential. In the last two decades, the automotive industry did make an exponential growth in producing fuel efficient cars, but still the automobiles do not operate at their fullest fuel efficiencies. This limitation is a result of the failure to adhere to optimum operating conditions. The problem of arriving at the optimum levels of the external factors has attracted the attention of the researchers and practicing engineers for many years.

The fuel economy, safety and reliability have become dominating factors for the car users in choosing a vehicle. Several investigators have attempted to improve the fuel economy of automobiles by researching on aerodynamics, light weight engines, fuel additives, injection system, power transmission and improvements in thermal and mechanical efficiencies along with hybrid technology and training manpower. In general, the causes and the use of various approaches adopted by the automobile manufacturers to optimize fuel economy. However, very little quantitative research work seems to have been carried out on how to enhance fuel economy of automobiles by optimizing the external factors such as tyre pressure, load, speed, windows status, road condition and tyre condition.

Starting at this juncture, in this work a pilot study is first carried out to understand the effect of the external factors on the fuel economy of an automobile. As a part of the pilot study, leak test, foot print analysis, fuel consumption test and speed tests are conducted.

It is observed from the leak test that under the dynamic conditions, the tyre pressure initially goes up in the first week due to the increase in energy of the air molecules in the tyre. i.e. at low temperatures, the water molecules in air occupy very little volume. However, as the temperature increases, liquid water vaporizes to become gas and its volume expands resulting in higher tyre pressure. As time passes, the tyre pressure declines because the increase in energy induces gas leakages.

Foot print is the portion of the tyre that is in contact with road surface. The foot print analysis provided an insight on the behaviour of the tyre with respect to load acting at the axle, which results in rolling resistance. As a part of findings, the contact area of tyres with the ground is measured on a hard concrete surface. The contact area for different tyre inflation pressures reveal that the fuel economy decreases with the increase in contact area.

The fuel consumption test in this first stage of work is used to assess the change in fuel consumption due to loss in tyre pressure under different driving conditions. It is clear from the study that as the tyre pressure drops; the tyre-road surface contact area increases resulting in higher rolling resistance. As the rolling resistance increased, it drew more energy (fuel) to get the automobile to the same distance, thereby reducing the fuel economy of the automobile.

The speed test reveals that a non-linear relationship exists between fuel economy and vehicle speed. It is noticed that as the vehicle speed increased the fuel economy increases up to a certain stage; corresponding to further increase in vehicle speed, the fuel economy gradually declined.

The pilot study confirmed that the tyre-road contact geometry, tyre inflate pressure, road condition, tyre condition and vehicle speed cause considerable variation in the rolling resistance. This rolling resistance can pose a varying load on the vehicle's engine, causing significant differences in fuel economy.

Based on the above, the core research problem is defined with an objective to investigate the optimal levels of external factors in order as to optimize the fuel economy of an automobile.

The experimental design process adopted viz., *Dr. G Taguchi's method* comprises of three main phases, namely system design, factor design and tolerance design. The factor design of Dr. G Taguchi's method has been used in this study.

The first step in Dr. G Taguchi's method is to state the objective of the experiment (Objective in this work: enhance fuel economy). The second step is a brain-storming exercise to identify the controllable and noise factors which have an impact on the fuel economy. Automobile service engineers from various service stations took part in the brain-storming exercise to identify the external factors that influence fuel economy of an automobile.

Accordingly, the following external factors are identified:

- Tyre pressure, vehicle speed and window status as '*controllable factors*'.
- Road condition and tyre condition as the '*noise factors*'.

The non-linear behaviour of the external factors can only be revealed if more than two levels of the factors are investigated. Hence, in this work, three levels are considered for each of the control factors selected. Since all the causative factors are selected at three levels, a Liner graph of configuration L_9 is found to be suitable for the experimentation.

The next step is to conduct the matrix experiments for loads ranging from single to five occupants and to record the response (fuel economy). The experiments are conducted using the chassis dynamometer (for Off-Road tests) and on test track (for On-Track tests) under “Highway” and “City” drive conditions as recommended by the Society of Automotive Engineers (SAE).

Accordingly,

- The highway test is to cover a distance of 16.1 km, with the vehicle driven at an average speed with very little idling and no stops.
- City test is for a distance of 17.7 km trip with 23 stops, the vehicle being driven at an average speed. About 18% of the time in the test is spent idling in-order to simulate waiting in traffic lights.

The off-road tests are conducted on the custom-made roller test bench (that is specifically designed, fabricated and installed at the laboratory). The on-track tests are conducted on the “Hi-tech test track facility” of the Bengaluru Metropolitan Transport Corporation (BMTC) at Bengaluru.

To analyze the results, Dr. G Taguchi’s Signal-to-Noise (S/N) ratio approach is used. The S/N ratio is the ratio of mean (signal) to the standard deviation (noise). S/N ratio equation depends on the criterion for the quality characteristic to be optimized i.e. Larger-the-Better, Nominal-the-Best or Smaller-the-Better. In this study, Larger-the-Better is considered as the most appropriate for optimizing the fuel economy.

The outcome of the study indicates that under highway driving conditions, the optimum fuel economy is attained at

- 2.18 kg/cm² (31 psi) tyre pressure and 55-60 km/h vehicle speed for single and double occupancy.

- 2.25 kg/cm² (32 psi) tyre pressure and 55-60 km/h vehicle speed for triple occupancy, and
- 2.25 kg/cm² (32 psi) tyre pressure and 50-55 km/h vehicle speed for four and five occupancy.

Similarly, under city driving, the optimum fuel economy is attained at

- 2.18 kg/cm² (31 psi) tyre pressure and 45-50 km/h vehicle speed for single and double occupancy
- 2.25 kg/cm² (32 psi) tyre pressure and 45-50 km/h vehicle speed for three, four and five occupancy.

Further, it is noticed that the windows in 'full close' status compliment fuel economy both under highway and city driving conditions, irrespective of the number of occupants.

It is observed that by setting the optimal levels of external factors depending on the number of occupants (single to five), the fuel economy improved up to 3.83 % under highway and 3.50 % under city driving conditions. This is a substantial improvement in fuel economy at large that not only results in an appreciable revenue savings, but also results in lesser dependency on fossil fuel and fewer pollutants released to the atmosphere.

This is followed by the development of regression equations through multiple regression analysis, in order to predict the fuel economy under highway and city driving conditions for various tyre pressure, vehicle speeds, windows' status and load profiles. Subsequently, the equations are validated using the real life data.

On the whole, the work clearly indicates that there is ample scope for fuel economy improvement by installing a Tyre Pressure Control System (TPCS) in an automobile and driven at the optimal levels of the factors (viz., the number of occupants, vehicle speed and the tyre pressure) under different driving conditions.