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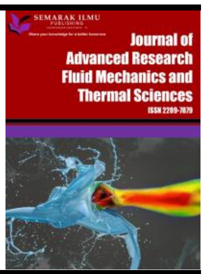


# Effect of Gear Usage on the Fuel Consumption of Light Duty Vehicle by Using On-Board Diagnostics (OBD) Data

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**ABSTRACT**

Transmission gear ratio usually affects transportation fuel usage during travelled on road. The manner of gear usage is one of the main factors affecting the fuel consumption of vehicles. By using the neutralizing driving data collection, the vehicle Toyota Hilux 2.5 liters has been used to conduct the experiment to determine the fuel consumption, based on the average vehicle speed, engine speed and gear usage. Some parameters were investigated, with a special emphasis on the relation between the engine speeds and vehicle speeds, also presenting an example of using the information provided by the OBD to determine the gear ratios. In the end, the gear steps and the way they are used while driving the vehicle were identified. It is found that each gear usage can have a specific impact on fuel consumption and the usage of first gear indicates higher average fuel consumption with 60.5% with 35.8 liters/100km compared with second gear. In conclusion, the fuel consumption is significantly determined by a proper gear selection.

## 1. Introduction

The OBD system has been introduced to monitor vehicle characteristic. For this purpose, it monitors a multitude of engine parameters and, if necessary, it can provide this information to the user or authorities. Access to this information is done with specialized equipment but cannot be restricted according to current standards. The continuous development of electronic control of car systems has determined an increasing of information available via OBD as used by Ameen *et al.,* [1]. Although access to these data is now easier than ever, the data retrieved still needs to be processed and interpreted.

A model able to detect active gear using data measured only by the OBD port is developed and validated over experimental results as conducted by Micu *et al.,* [2], where a suitable mix of filtering algorithms and rules has allowed overcoming the problems due to uncertainty and discretization error in OBD velocity data. Previous studies as conducted by Shinaar *et al.,* point out with arguments, that manual gear shifting may be considered as an automatic process performed routinely, but only

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for experienced drivers. On the other hand, for drivers who have just been granted driving license this process requires a mental effort. Automation is therefore achieved through experience, which is mostly independently acquired by a driver [3].

Ramasamy has previously built a brake specific fuel consumption (BSFC) map for K3-VE Perodua Myvi engine that presents the fuel consumption at wide-open throttle (WOT) condition. However, the map is not enough for vehicle simulations that estimate fuel economy. This is because any vehicle simulation would use broad range of speed and torque and not only at WOT condition [4].

In addition, by a detailed analysis of the relation between a driver's behaviour and fuel consumption, it was proved that those elements of driver's behaviour, related to gear selection, vehicle speed and acceleration and/or deceleration have the largest influence on fuel consumption as discovered by De Vlieger *et al.,* They found that the fuel consumption at the same average driving speed can be increased up to 20% only due to difference in the manner of gear shifting [5]. Usually, the information about the selected gear is available on the OBD but in this experiment that information is not included in this the vehicle. This paper proposes a relatively simple method by which the gear engaged at a given moment can be determined when the information about the selected gear is not available and aims to analyse a series of data from a Toyota Hilux, equipped with manual transmission, in multiple traffic condition. Some parameters are analyzed, with a special emphasis on the relation between the engine speed and vehicle speed, defining and explaining their ratio. The ultimate goal is to determine the gears and their effect to fuel consumption while driving the vehicle.

## 2. Methodology

### *2.1 Vehicle Test Specification*

The vehicle tested is a 2.5-liter, four-cylinder light-duty vehicle with four-stroke engines. This model of the vehicle was selected because of its success as the main fleet as proven with higher selling units compared with other manufacturers [6]. A description of the specification of the vehicle is presented in Table 1. It uses a diesel direct injection rail system [7]. Such a form of the engine has a wide demand in Malaysia, where this research is taking place. Therefore, the light-duty vehicle selected for this study would be beneficial to such a population [8].

**Table 1**
Specification of the engine [6]

| Type | Description |
|---|---|
| Engine | 2.5-liter D-4D Diesel |
| No. of cylinders | 4 cylinders |
| Engine capacity | 2494cc |
| Stroke | 93.8mm |
| Bore | 92mm |
| Connecting rod | 158.5mm |
| Compression ratio | 18.5:1 |
| Exhaust valve open | 30° BBDC |
| Exhaust valve close | 0° BTDC |
| Intake valve open | 2° BTDC |
| Intake valve close | 31° ABDC |

### *2.2 Test Route*

The route chosen is a section of the high-frequently route, which has a length of 263 km. The route is long enough to measure the effects of accurate fuel efficiency The explanation that this route section was analyzed is; this route of the line is the longest part of this dedicated route with different operating characteristics and since the selected route (i.e., the Northbound route) belongs to a road connecting the downtown and suburban residential areas, the traffic has obviously related characteristics, which facilitates subsequent analysis of peak and off-peak hours.

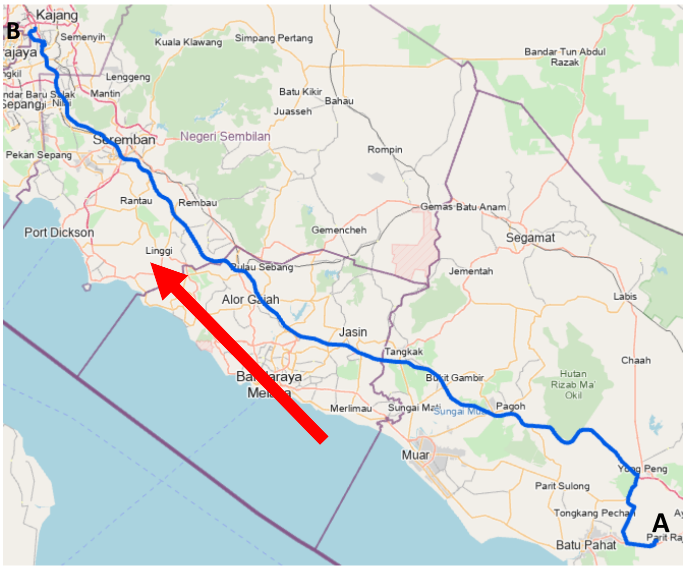


**Fig. 1.** Selected experimental route for field data

The experiments were carried out during the daytime. This data collection is adequate to produce accurate performance. The same driver drove the vehicle during all the experiments. The location of the vehicle throughout the field trial was tracked by GPS equipment.

In order to analyse the real driving, the real driving data of the vehicle were collected through OBD vehicle. Figure 2 shows an overall structure of the in-vehicle data flow. Bosch KTS 570 Vehicle Diagnostic Scan Tool was connected through the On-Board Diagnostics II (OBD II) protocol. The measured data were logged using the screen recoding. The real-time acquisition was synchronized and recorded at 100 Hz.


**Fig. 2.** OBD configuration

### *2.3 Naturalistic Driving Data Collection*

Naturalistic driving refers to participants who drive according to their everyday needs and driving behaviours as conducted by Kumar Pathak *et al.,* [9]. On-board data collection systems track and report driving information for the driver (Holden *et al.,*) [10]. This data collection process is relatively expensive and the data screening process is complicated, but natural driving data will show real driving behaviour of drivers under current traffic conditions as conducted by Ragione *et al.,* [11]. Therefore, in order to ensure the reliability and representativeness of our findings of research, we used naturalistic driving data in this research.

The approach listed here only addresses on variations of the on-road driving condition and does not include external variables that can impact on-road fuel consumption, including the thermal status of powertrain components, vehicle dynamics and environmental conditions.

A free-driving scenario refers to a situation in which the vehicle runs freely. In the free-driving scenario, since there is no disturbance affecting the speed of the vehicle, the driver can operate the vehicle as they wish. Therefore, by analysing the vehicle behaviour in the free-driving scenario, it is possible to investigate the driver's preferred driving style. However, even if there are no obstacles around the vehicle, driving behaviour may be affected according to information pertaining to traffic or other external influences on the road. For example, the vehicle may start after being stopped by a stop signal from a traffic light, or it may accelerate again after decelerating during a right turn at an intersection. In such a situation, the driver's tendency for acceleration, deceleration, and stopping also can change related to topography of the road.

### *2.4 Measuring Engine and Vehicle Speed*

The data shown on the charts offer a multitude of information about the vehicle and the engine. For a better approach, the data are analysed separately, but not without considering the influences from the other parameters. To analyse the relation between the engine speed and the vehicle speed, and to determine the gears and their using, a short period from a trip was chosen and the data were processed in Excel.

The engine speed values and the vehicle speed values were inserted in Excel and their ratio (n/V) was computed for every second. In Figure 4 shows the unfiltered data of RPM versus speed. Each of the spokes in the graph above belongs to a different gear. Higher gears give a higher speed for the same RPM.

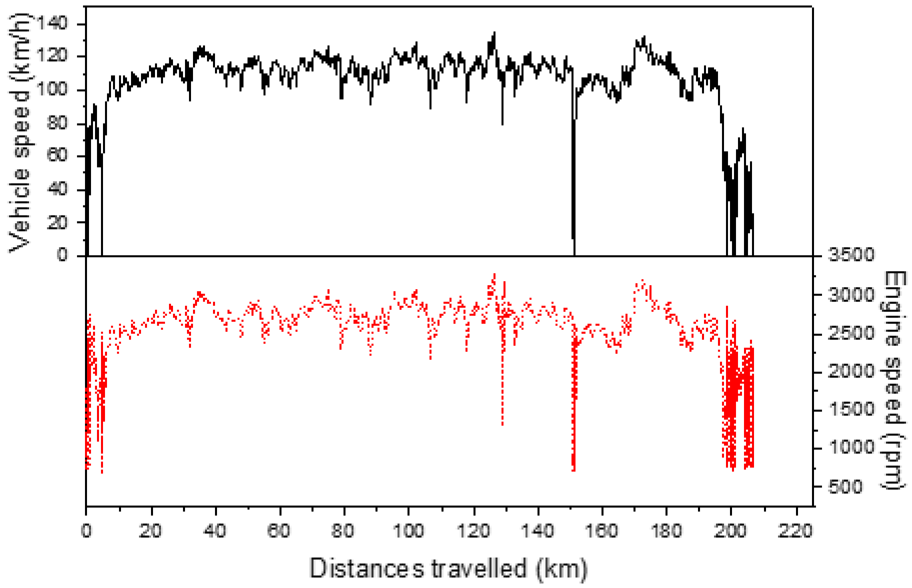


**Fig. 3.** Vehicle speed and engine speed variation in period selected to be analyzed

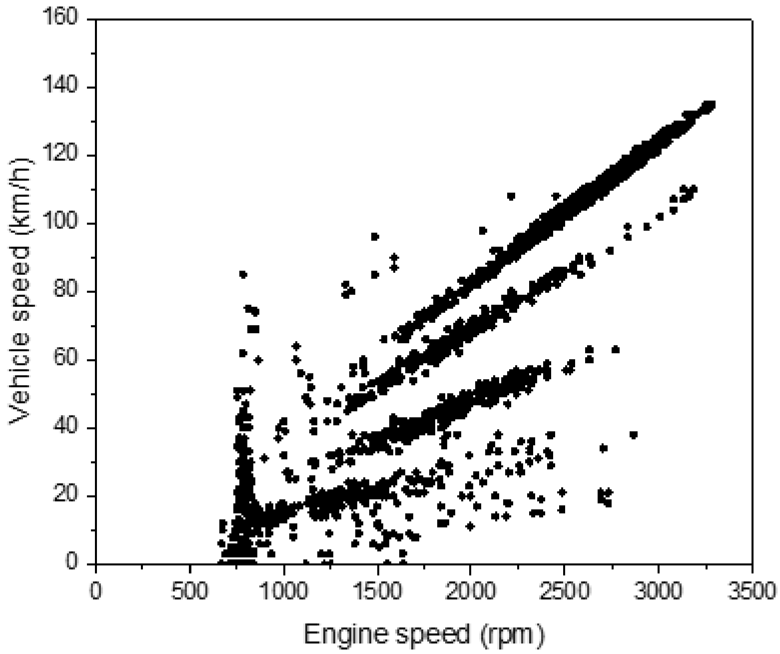


**Fig. 4.** Engine speed against vehicle speed

There is a clear tendency of these values to distribute after some oblique lines, whose slope depends on the transfer ratio of the transmission [12]. Since the slope of these lines is actually the n/V ratio, it results that this is not only the transmission ratio but a global ratio between engine speed and vehicle speed, which included the final transmission ratio and rolling radius of tier, besides gear ratio.

The unit of measure for this global ratio "R" will be [rev*h /min*km] or, after reduction of time units, the units will become [rev/km]. This means that if the global ratio "R" will be multiplied by 60, the result will show how many revolutions of the engine are necessary to travel one km, for a certain gear. Therefore, the global ratio of the vehicle can be very useful in modelling, because it comprises all the cinematic aspects regarding transmission of the power from engine to road (gear ratio, final ratio, rolling radius) and could be used as a transfer function for a "black box" transmission.

## 3. Result and Discussion

Apparently, the vehicle seems to be equipped with a 5-speed gearbox. To determine the right transmission ratios, these intermediate points are removed and only those whose n/v ratios are close to the predetermined ±5% are selected from all data. The selected data are sorted by the value of this ratio and they are shown in Figure 5 separately by groups of values so that they can be distinguished. A trend line is assigned to each point group.

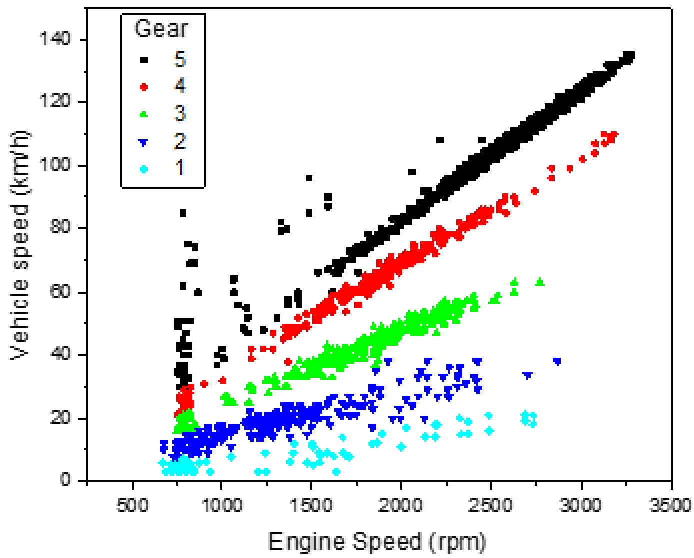


**Fig. 5.** Correlation between engine speeds and vehicle speeds for all gears

As previously mentioned, the overall gear ratio R comprises gear ratio, final transmission ratio and rolling radius. It follows that the dimensions of the tires (which is stored in the car's computer memory) and the final transmission ratio (which can be found on certain profile sites) must be known to compute the correct gear ratio. Values of gear ratios only are from 3.520 for the first gear until 0.716 for the fifth gear. Issues of gear shifting optimization still represent actual challenge to scientific-expert potential in the field of transportation vehicles.

However, the ratio of R is enough to identify the gears. The corresponding gear is identified for values close to those shown in Figure 6. An intermediate gear which will Show the gears changes will be considered for intermediate values, according to Table 2. Value 0 is considered for the neutral gear. For first gear, the range of gear ratio contributed within range higher than 3.280. Next for second gear, the calculation gear ratio shown in range of 3.280 and 1.500. Then, followed by gear ratio 1.500 and 1.079 under third gear. For forth gear, by calculation the gear ratio indicated under range 1.079 and 0.888.

All data is reordered according to time after that the gear for each second is known. The engine speed, the vehicle speed and the used gear is graphically shown in Figure 6. For a better graphic representation, the speed is displayed at range 200-206km distances travelled since earlier range distribution only in fifth gear usage. Given the proximity between the engine speed scale and the R ratio value for the last gear (fifth), the velocity and speed graphs overlap. From Figure 6, its shows transition from one gear ratio to another, the engine must be accelerated when gearing down or decelerated when gearing up to reach the new engine speed it can be establish as discovered by Ivarsson *et al.,* [13].

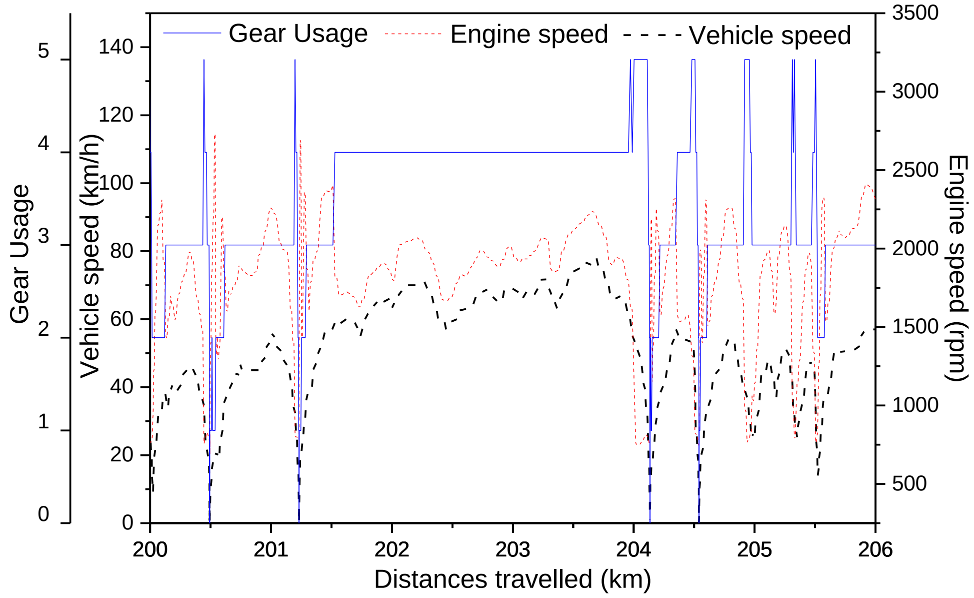


**Fig. 6.** Engine speed, vehicle speed and their corresponding computed gears.

**Table 2**
The gears usage according to the values of the R ratio.

| Gear indicator | Actual Gear ratio | Calculation Gear ratio (R) |
|---|---|---|
| N | 0 | R=0 |
| 1 | 3.52 | R>3.280 |
| 2 | 2.042 | 3.280<R>1.500 |
| 3 | 1.4 | 1.500<R>1.079 |
| 4 | 1 | 1.079<R>0.888 |
| 5 | 0.716 | 0.888<R |

From Figure 7, the figure shows the relationship of the engine speed against gear usage. the lowest rpm recorded within the trip was in range of 590 to 816 rpm at all range gear usage except fifth gear. The maximum of rpm recorded under first gear shown at 2730 rpm. The usage of third gear shown the lowest average contribution of engine speed distribution at 1268 rpm. The engine rpm recorded under fifth gear shown in range of 2091 to 3256 rpm, the highest rpm can be identified as the usage of fifth gear has been use in highway with clear traffic and less disturbing the vehicle travelled. From the figure, the second gear covered most if the engine speed range with 82.4% (over overall engine speed) then followed by first, forth, third and fifth gear with 76.55%, 73.1%, 58.2% and 43.6% respectively.

From Figure 8, the graph shows relation of vehicle speed and the gear usage during travelled on the tested road. From the figure, usage of first gear contributes vehicle speed within range of 4.4 to 21 km/h. Next, for the first gear usage contribute vehicle speed in range of 6-38 km/h, then for the third gear, the lowest vehicle speed recorded at 10 km/h and 38 km/h at higher vehicle speed. Meanwhile for forth gear usage, the vehicle travelled within speed range of 19-63km/h. From usage of fifth gear, there are slightly higher compared to other gear usage with vehicle speed in range of 86-134km/h.

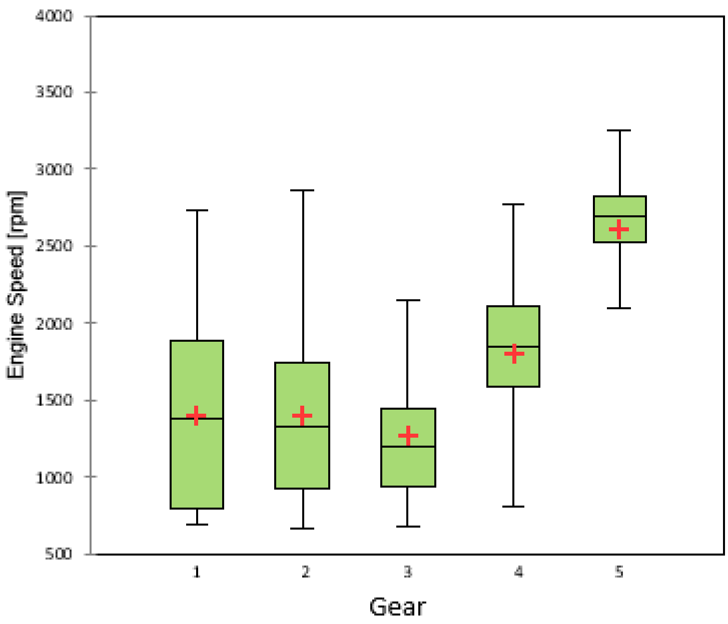


**Fig. 7.** Engine speed again gear usage

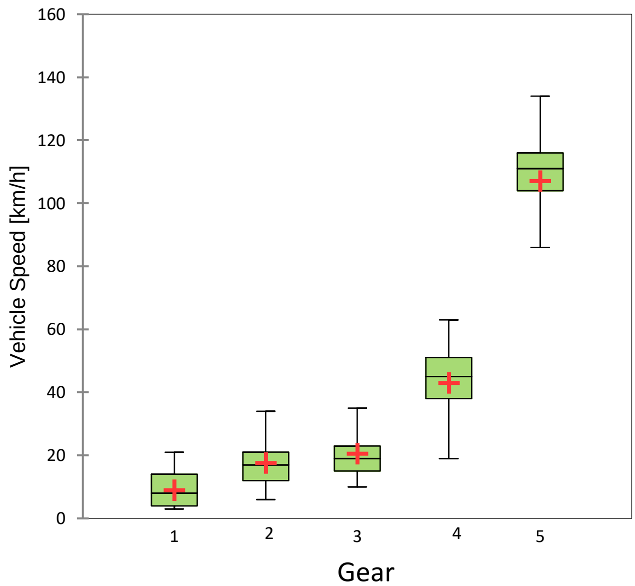


**Fig. 8.** Vehicle speed again gear usage

From the figure, the higher of vehicle speed can be contribution due to higher engine speed at lower interruption of the traffic especially in highway road. Each gear has an optimum speed, beyond which fuel efficiency will be drops. This optimum speed is often called the sweet spot. By the reasoning above it is understood that the gear-shifting process does affect vehicle speed directly due to a low propulsion during gear shift. But more importantly, as discovered by Borisov *et al.,* [14] by gearing down early a high engine speed and consequently a high engine power are obtained throughout the slope, and the case can accordingly keep a higher vehicle speed throughout the uphill.

Assuming crowded roads such that the average vehicle speed cannot be increased shows the fuel consumption is most sensitive to overall average vehicle speed. At the relatively low speeds especially at urban route, the dominant cause of fuel use is generalized engine friction, which is proportional to the number of engine speed in the trip as discovered by Sigh *et al.,* [15]. Meanwhile Berry *et al.,* says that if the vehicle speed is increased while engine speeds remain about the same, the trip time decreases and the total number of engine speed is decreased [16].

To make a comparison of the potential for reduction of fuel consumption by a selection of optimal gear in real traffic conditions, for conditions of the driving in a lower than optimal gear, the average reduction factor of fuel consumption after selection of higher gear was determined. From Figure 9, the graph shows the relationship of fuel consumption and gear usage. The resents the lowest fuel consumption to perform at the fifth gear usage, presenting 9.757 liters/100km as compared to the standard solution. The highest contribution of fuel consumption shown in usage of the first gear with average 35.86 liters/100km then followed by gear first, third, and forth with 22.31, 11.14 and 10.17 liters/100km respectively. Fuel consumption improves at a higher gear and while driving at higher speeds under highways condition, higher the gear better is the fuel consumption. These phenomena can be proved by Gunawan *et al.,* which they discovered that fuel consumption is also sensitive to free-flow velocity [17].

From Figure 9, by using differences gear show significant saving in fuel consumption. From the figure, by using of first gear, the fuel consumption increases about 60.5% compared with second gear. Meanwhile by using the fifth gear give reduction of fuel consumption about 4.3% compared with forth gear under high vehicle speed at average speed 107km/h. Other than that, the maximum vehicle speed is assumed to achieve the power in the worst case scenario as discovered by Norbakyah and Salisa [18].

From the data quoted above, it can be seen that the fuel consumption reduction effectiveness resulting from the selection of the proper gear will be significantly determined by individual driving behaviour. When gearing up, the engine is decelerated by the engine drag torque meanwhile when gearing down the engine speed is performed by injecting fuel [19].

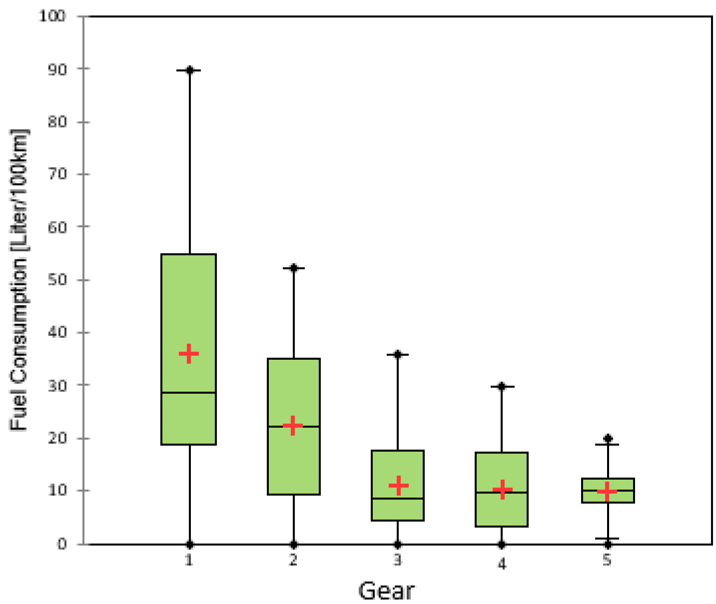


**Fig. 9.** Fuel consumption again gear usage

## 4. Conclusion

In this study the authors analysed the potential reduction in fuel consumption under real driving conditions, resulting from the selection of the optimal gear. The applied methodology required the collection of a large amount of data and simultaneous usage of models to estimate the fuel consumption in relation to the actual gear usage and vehicle speed. As a result of the analyses performed, it has been found that

i. Every gear usage can have a specific impact on fuel consumption.
ii. Individual performance metrics can show high sensitivity to fuel consumption, gear 5 and lower engine rpm, in particular the 80-140 km/h passing times
iii. The usage of first gear indicates higher average fuel consumption with 60.5% with 35.8 liters/100km compared with second gear.
iv. The lowest fuel consumption recorded under fifth gear with 9.75 liters/100km which reduction 4.3% reduction compared with gear forth.

In summary, it was shown that due to the selection of the appropriate gear, there still exists a real possibility of reduction of fuel consumption, even in the case of experienced drivers. The results show also the limitations of the real fuel-saving resulting from the selection of the optimal gear according to vehicle speed and engine speed. Many interesting comparisons were beyond the scope of this paper and the data presented here are only a sample of the study results, but future work may include a study of the effects of engine load and route type and road grade.

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