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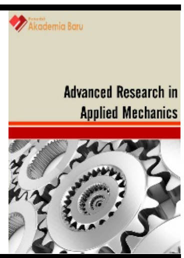

Characterization of Gear Usage to Fuel Consumption of a Light Duty Vehicle from Direct Measurements by Using On-Board Diagnostics (OBD) Data

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ABSTRACT

Transportation contributes a major share of the fuel usage from total vehicles in developing countries. The manner of gear usage is one of the main factors affecting the fuel consumption of motor vehicles. The presented results came from the tests conducted on Toyota Hilux 2.5 liters vehicle to determine the fuel consumption, based on the average vehicle speed, engine speed and gear usage collected from using the neutralizing driving data collection. 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 lowest fuel consumption recorded under fifth gear with 9.75 liters/100km which reduction of 4.3% reduction compared with 4th gear. In conclusion, the fuel consumption is significantly determined by a proper gear selection.

Keywords:
Gear usage; Driving behaviour; light-duty vehicle; naturalistic driving

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1. Introduction

The OBD system has been introduced to monitor vehicle characteristics. 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,

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that manual gear shifting may be considered as an automatic process performed routinely, but only for experienced drivers. On the other hand, for drivers who have just been granted driving licenses this process requires a mental effort. Automation is therefore achieved through experience, which is mostly independently acquired by a driver [3].

Usually, the information about the selected gear is available on the OBD but in this experiment that information is not included in this 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 a 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. 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 [7].

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

2.1 *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.

In order to analyse the real driving, the real driving data of the vehicle were collected through the OBD vehicle. **Error! Reference source not found.** 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 recording. The real-time acquisition was synchronized and recorded at 100 Hz.

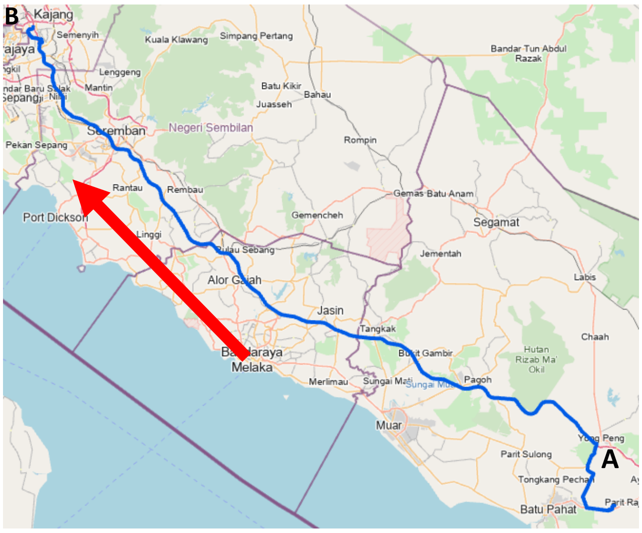

Fig. 1. Selected experimental route for field data

2.2 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 relationship between the engine speed and the vehicle speed, and to determine the gears and their use, 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. Fig. **3** 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.

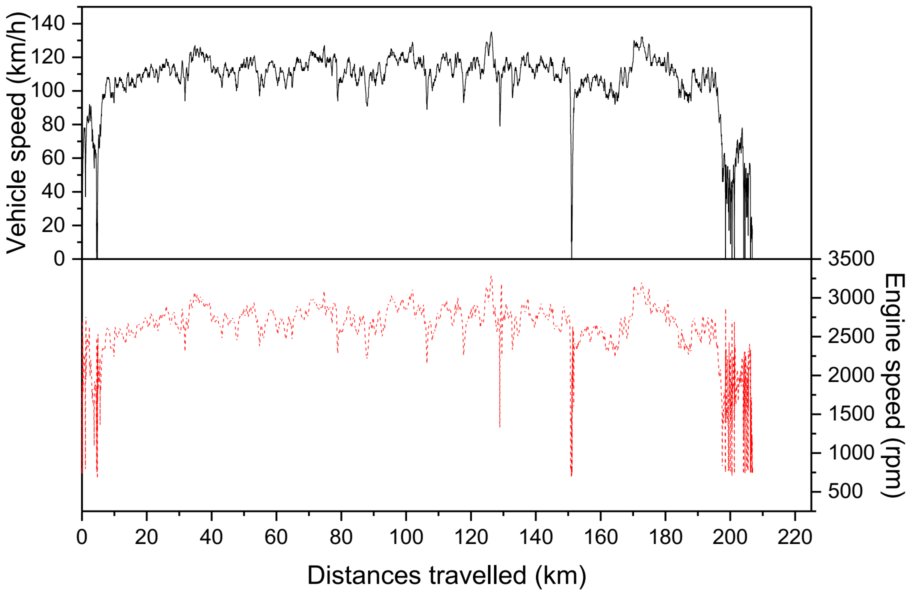

Fig. 2. Vehicle speed and engine speed variation in the period selected to be analyzed

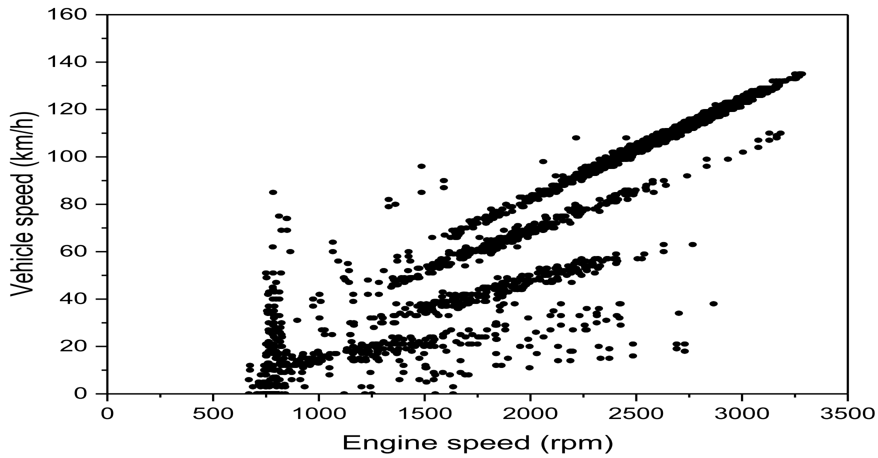

Fig. 3. Engine speed against vehicle speed

There is a clear tendency of these values to distribute after some oblique lines, whose slope depends on the transfer ratio of the transmission. 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 the 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.

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.

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.

However, the ratio of R is enough to identify the gears. The corresponding gear is identified for values close to those shown in Fig. **5**. An intermediate gear that will show the gears changes will be considered for intermediate values, according to Table 2. 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 are graphically shown in Fig. **5**. For a better graphic representation, the speed is displayed at range 200-206km distances travelled since earlier range distribution only in fifth gear usage.

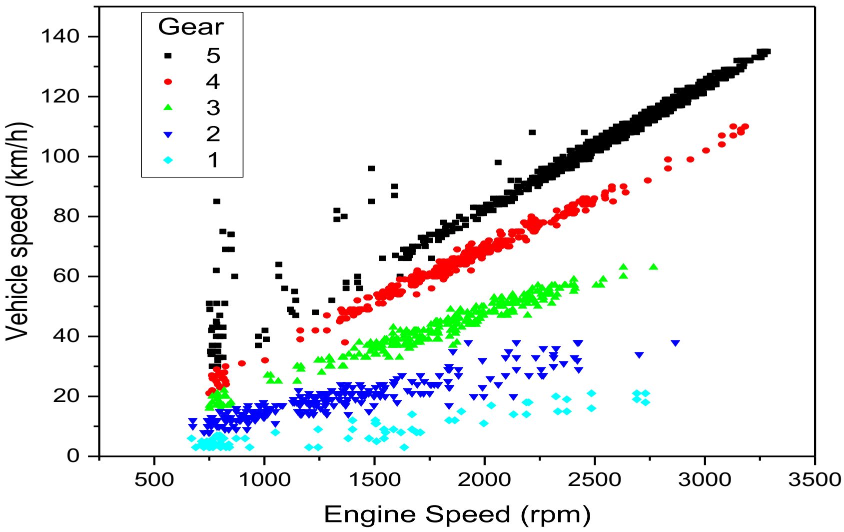

Fig. 4. Correlation between engine speeds and vehicle speeds for all gears

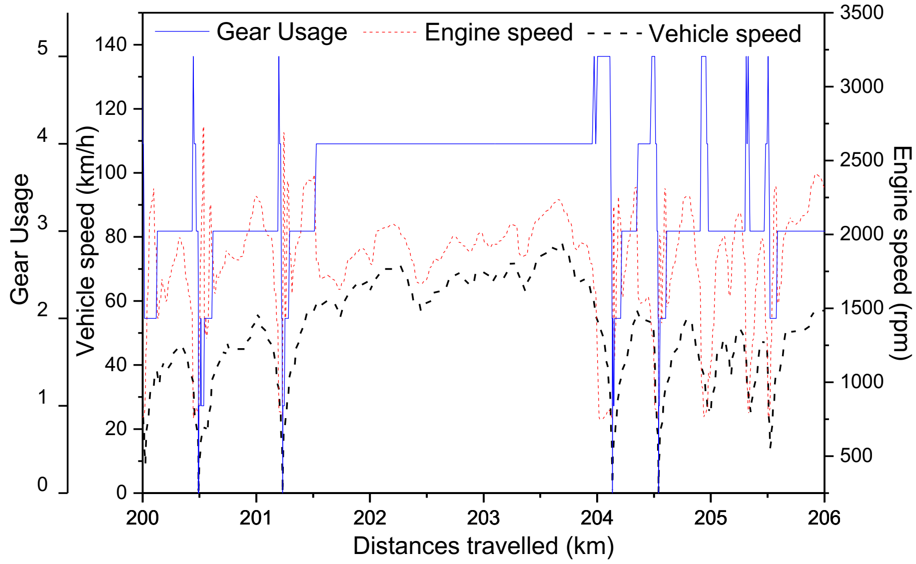

Fig. 5. Engine speed, vehicle speed and their corresponding computed gears.

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

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. 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.

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