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O.B.D-2 sensor diagnostics for monitoring vehicle engine load

Chariton Christoforidis [1,*], Dimitrios E. Barkas [2], Ioannis Christakis [3] and Dimitrios Rimpas [3]

[1] *Hellenic Electricity Distribution Network Operator S.A., Perevou & Kallirois 5, 11743 Athens, Greece.*

[2] *Laboratory of Sustainable Systems and Resilient Infrastructures, Department of Surveying & Geoinformatics Engineering, University of West Attica, Agiou Spyridonos 28, 12243 Egaleo, Greece.*

[3] *Department of Electrical and Electronic Engineering, University of West Attica, P. Ralli & Thivon 250, 12244 Egaleo, Greece.*

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Abstract

The increasing need for efficient vehicle diagnostics and performance optimization has led to advancements in On-Board Diagnostics (O.B.D) systems, particularly the O.B.D-2 protocol. This study investigates the real-time monitoring capabilities of O.B.D-2 for assessing engine load under various driving conditions. Three different vehicles were examined, and key parameters such as vehicle speed, engine speed, throttle position, and engine load were analyzed. Results indicated that engine load increases significantly when vehicle speed is low while Rounds per Minute (RPM) remain high. Conversely, when speed increases and engine speed reach the optimal range of 2000 to 3000 RPM, the total engine load decreases, indicating optimized engine performance. These findings highlight the potential of O.B.D-2 for real-time diagnostics and fuel efficiency improvements. The study also discusses the limitations of O.B.D-2 and future advancements in O.B.D-3, which promise enhanced real-time data transmission and remote monitoring. The implementation of next-generation diagnostic systems could play a crucial role in reducing emissions and improving vehicle maintenance strategies.

Keywords: Vehicle; I.C.E; CAN-Bus; O.B.D; Engine Load

1. Introduction

World transportation was greatly impacted by the internal combustion engine (I.C.E), which is considered one of the century most significant technologies [1].

Figure 1 Four cylinder internal combustion engine [2]

* Corresponding author: Chariton Christoforidis

The late 1860s marked the successful development and invention of the I.C.E due to its design, high power-to-weight ratio, dependability, and longevity. A typical internal combustion engine is displayed at Figure 1 below, with 4 cylinders in a row array, while each chamber includes an intake and exhaust valve for the air-fuel mixture to enter and exit the combustion chamber [2].

I.C.Es are heat engines, designed to convert the heat energy produced by the combustion of air and fuel, typically gasoline, mixture into mechanical power [2]. A full operational cycle requires four distinct piston strokes, which are defined as the piston displacement from the top dead center to the bottom dead center and vice versa. The four-stroke operating cycle is summarized as follows [3]:

- Intake: The piston moves from the top dead center to the bottom dead center, while the intake valve is open. The mixture enters the combustion chamber and due to the closed exhaust valve, pressure remains constant.
- Compression: The piston moves towards the top dead center and compresses the air-fuel mixture. The intake-exhaust valves are closed, resulting in increased pressure.
- Combustion: The increase of temperature combined with the spark provided by the spark plugs, ignites the mixture leading to the piston downstream producing power for vehicle propulsion. The intake-exhaust valves remain closed.
- Exhaust: With the exhaust valve now open, the piston returning upwards, pushes the gases into the exhaust valve so that the cycle can restart.

Since conventional vehicles utilizing I.C.Es run on fossil fuels, they are directly related to environmental air pollution, while the harmful substances they emit have exacerbated the effects of climate change to human health [4-5]. For many years, manufacturers have been studying new technologies to reduce exhaust emissions and vehicle fuel consumption by utilizing modern sensors and control units to improve vehicle performance and efficiency [6]. The revolutionary technological advancements in automotive design necessitate a substantial increase in computing power, to support the numerous electronic systems, as well as the various programs that are necessary for safety and driver-supported features [7]. The sum of all greenhouse gases, expressed in tons of carbon dioxide equivalent are broken down by sector in Figure 2 [8]. The two biggest sources of emissions worldwide are the generation of heat and electricity while the transport sector, in general, is responsible for approximately 20% the world greenhouse gas emissions which have steadily risen over time as seen in Figure 2.

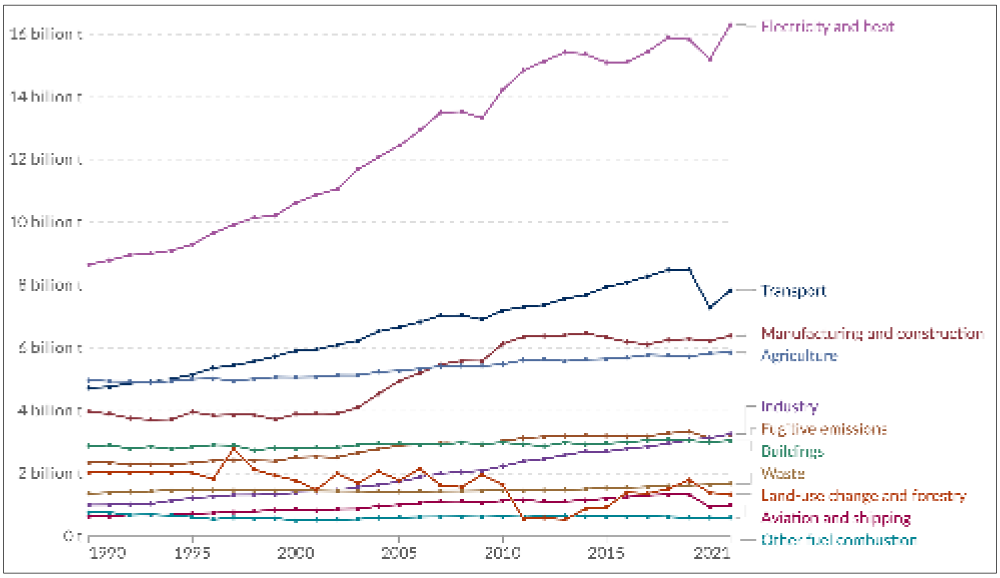


Figure 2 Greenhouse gas emissions by sector [8]

To monitor certain parameters and optimize the performance of modern vehicles, complex control modules are employed [9]. These electronic control units (E.C.U) are responsible for monitoring the vehicle electrical systems operation by processing data from several sensors, to control operations like fuel air mixture regulation or to identify possible faults [10]. There are different types of E.C.Us based on their operation while their placement inside the vehicle is critical to minimize communication delay and errors [11]. As modern vehicles require more E.C.Us for optimized performance, the deployment of real-time communication systems faces significant hurdles due to the limited bandwidth available [12]. A typical E.C.U layout for a conventional vehicle is displayed at Figure 3 below [13]:

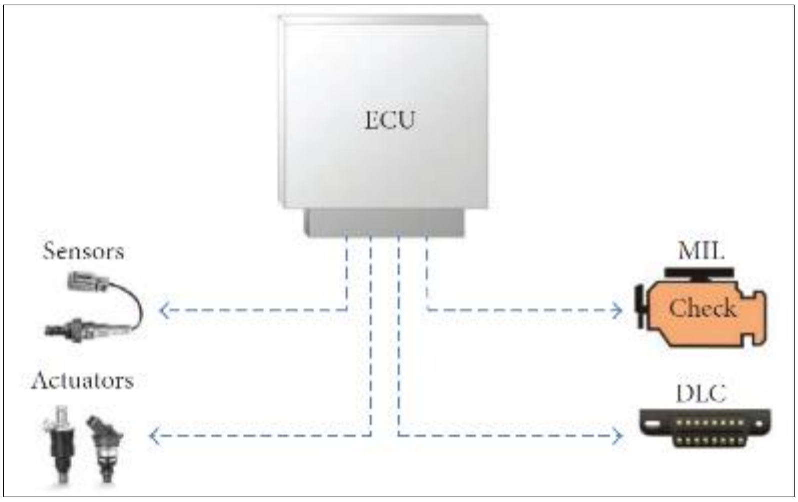


Figure 3 E.C.Us communication diagram [13]

In order to reduce lag and complexity of communication between various modules the Controller Area Network Bus (CAN-Bus) is introduced. CAN-Bus is a network channel created to provide effective unit-to-unit communication while allowing priorities in transmission depending on the signal ID [14]. All parts of the hardware and software layout are compatible for direct communication. So, CAN-Bus provides a simple single-pair bus for fast data transmission. This layout offers the ability to monitor and edit each parameter regardless of the source or processing techniques employed [15]. Figure 4 illustrates a connection diagram of the CAN-Bus communication system between different electronic units throughout the vehicle.

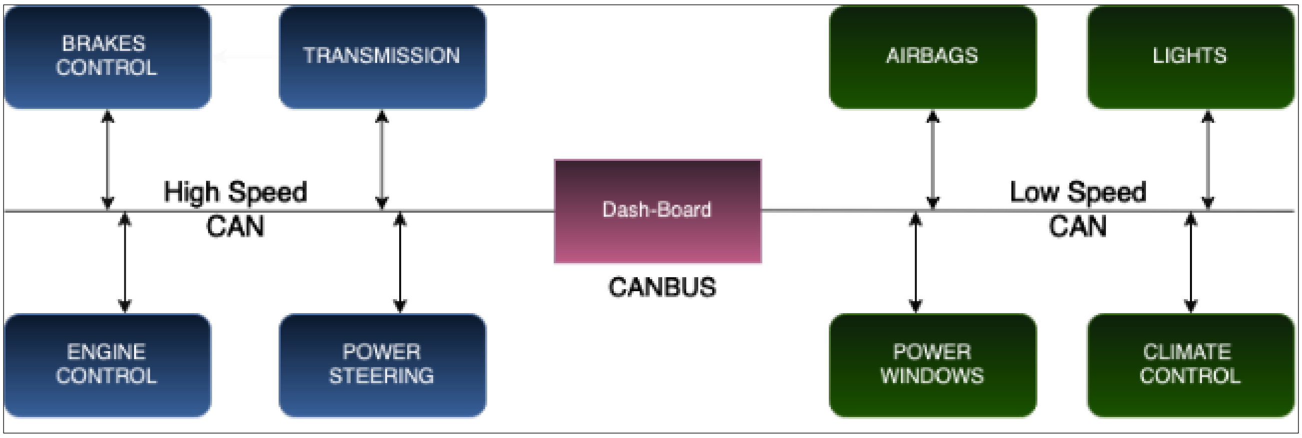


Figure 4 Connection between various E.C.Us using CAN-Bus [15]

As stated before, climate change is considered a major environmental issue while vehicle transportation is currently one of the main sources of CO_2 emissions [16], hence automobile manufacturers are obligated to minimize these pollutants [17]. Technological progress combined with the exhaust gases control strategies contributed to the development of a fault monitoring system [18]. On-Board Diagnostics (O.B.D) is a computer-based system designed to diagnose potential malfunctions in vehicles operation related to exhaust emissions [19]. It allows the user for access to the status of the vehicle subsystems at any given time through an O.B.D scanner [20-21].

The first O.B.D protocol included a standard E.C.U, for controlling the actuators and achieve the required performance utilizing input data from a small list of sensors, like the lambda sensor. A malfunction indication light, also referred as the "Check Engine", alerts the driver for malfunctions related to exhaust gases [20]. Using external diagnostic tools, a conventional vehicle diagnostic link connection (D.L.C) provides access to a plethora of parameters. However, the maintenance was troublesome due to the absence of a universal port [21]. In 1994, the O.B.D-2 protocol was introduced to address the shortcomings of O.B.D-1, where E.C.Us were gradually able to provide additional sensor data and diagnostic information as well as the real-time status of the systems based on sensor outputs. O.B.D-2 also provides diagnostic trouble codes (D.T.C) that were produced by the specified control module, while data can be extracted and stored via a cable, Wi-Fi or Bluetooth protocols [22-23]. Thus, the main advantage of O.B.D protocol is the potential for live fault diagnosis at each subsystem, sensor or actuator, so that it can be addressed immediately [24-25]. Figure 5 shows a standard O.B.D scanner and a 16-pin diagnostic connector found in conventional vehicle.

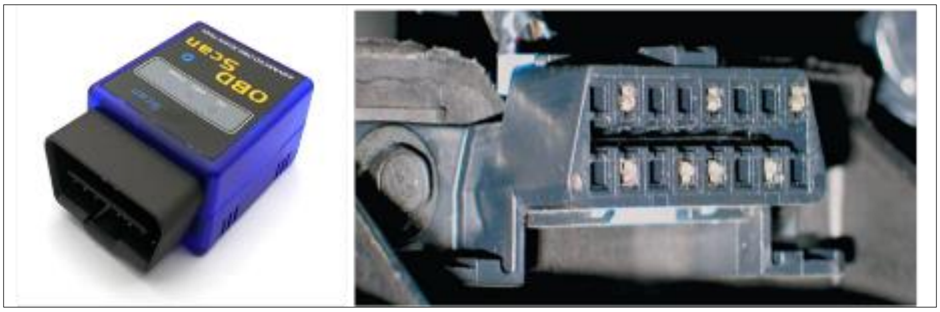


Figure 5 O.B.D-2 scanner and a standard 16-pin diagnostic connector [24-25]

Due to contemporary demands in lowering pollution levels for environmental preservation, automakers have incorporated new engine components and technologies that were not previously available [26]. The exhaust gas recirculation (E.G.R) valve technology was introduced to lower nitrogen oxide emissions by recirculating a part of the exhaust gases back into the intake to reburn. This procedure also stabilizes the temperature of the combustion chamber while reducing the unburnt fuel. Thus fuel economy is enhanced and the exhaust of dangerous emissions like carbon monoxide are decreased [27].

Engine performance has consistently been a subject of interest for experts seeking to accurately monitor, interpret, and enhance its utilization. In our work we have used the established methods, protocols, and tools to acquire sensor parameter values via the CAN-Bus using the O.B.D-2 protocol [28]. The selection of the most fitting parameters for monitoring was a pivotal aspect of our research, based on the influence of these parameters related to important composite parameters. In addition, the consequences of their potential malfunction, and the prospective benefits of obtaining them through the CAN-Bus for reading them via an O.B.D scanner are examined. Considering all of the aforementioned factors, the authors conducted a study to assess engine stress in vehicles by subjecting three different vehicles to diverse driving conditions and behaviors.

The manuscript is structed into three main sections: Section 2 describes the methodology used to conduct the experiment along with explanation of certain parameters utilized and their importance. In Section 3, the results of the experiment are presented and in the last section conclusions of this work are included along with suggestions for future work.

2. Methodology

The paper explores the application of the O.B.D-2 protocol for real-time engine stress monitoring across three different vehicles types (SUV, Class A and B), providing a comprehensive evaluation of their respective performance. In addition, the real-time fuel consumption data was analyzed to assess the relationship between vehicle speed, engine speed, and driving behavior (aggressive or conservative) on fuel efficiency. This study employed an empirical approach to investigate the efficacy of the O.B.D-2 protocol for real-time monitoring of engine load and its correlation with vehicle performance parameters under diverse operating conditions. The primary objective was to analyze how key vehicle metrics, accessible via the standard O.B.D-2 interface, reflect engine stress and efficiency across different vehicles and driving scenarios.

Three distinct vehicles were selected for the experimental phase to ensure the findings possess a degree of generalizability across different models and potentially engine types. The selection of monitored parameters was critical and based on their direct relevance to engine operation, load assessment, and fuel consumption analysis. The core parameters chosen for acquisition via the O.B.D-2 port are the following:

- Vehicle Speed (km/h): A fundamental indicator of the vehicle's operating state.

- Engine Speed (RPM): Directly relates to the engine's work rate and operating range.
- Throttle Position (%): Represents driver demand for power, indicating intended acceleration or load.
- Calculated Engine Load (%): A crucial composite parameter provided by the E.C.U, representing the current engine output relative to its maximum potential output at the current RPM. This parameter was central to assessing engine stress.

Additionally, real-time fuel consumption data was logged where available to correlate engine load and driving behavior with fuel efficiency. Data acquisition was performed using a commercially available ELM327 O.B.D-2 adapter, a widely used interface for accessing vehicle diagnostic data [25-26]. This adapter facilitated communication between the vehicle's Electronic Control Units (E.C.Us) via the Controller Area Network (CAN-Bus) through a data logging device. The ScanMaster application software was utilized to request, receive, and log the specified parameter IDs (P.I.Ds) corresponding to the selected metrics. The standard O.B.D-2 diagnostic connector, typically located within the vehicle cabin, provided the physical interface point shown in in Figure 6.

Figure 6 ELM327 scanner with Wi-Fi and Bluetooth compatibility

Each selected vehicle was subjected to a range of real-world driving conditions, encompassing variations in speed, acceleration, and potential traffic scenarios, to capture data across different engine load states. In Figure 7 below, testing with 8 different values was executed to confirm the liability of the results versus a renowned professional scanner with 100% accuracy.

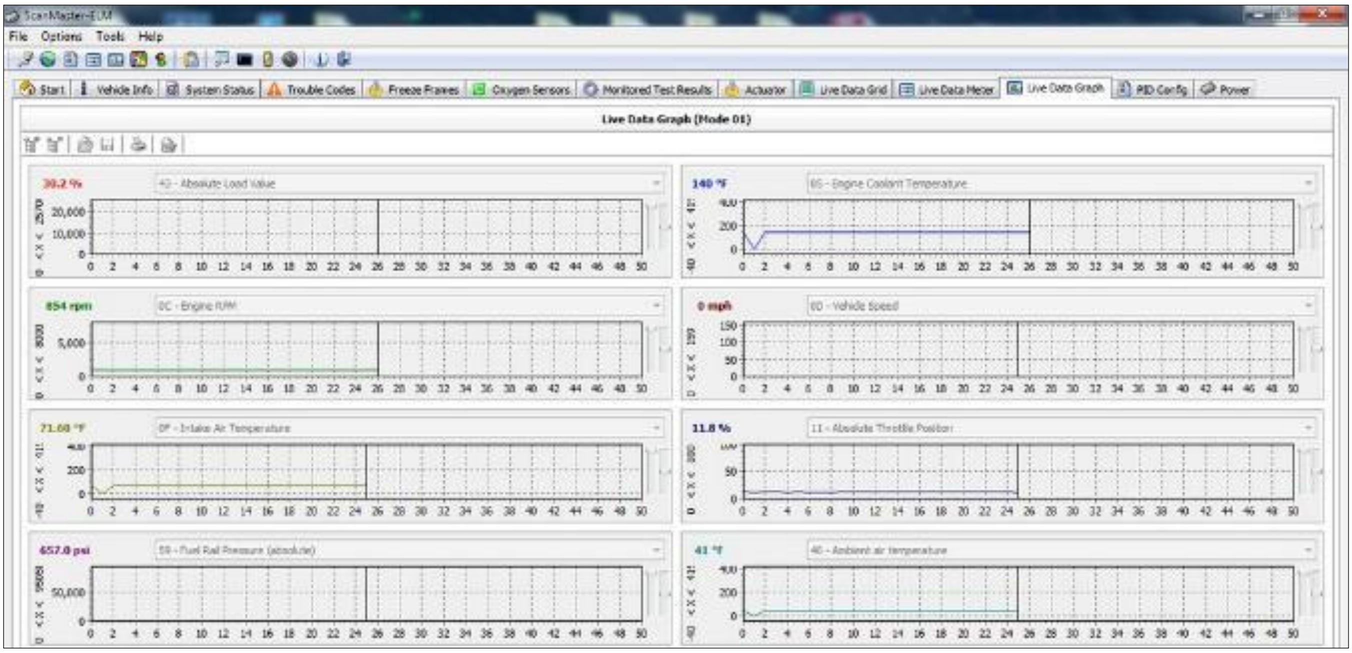


Figure 7 ScanMaster-Elm User Interface testing 8 different values

An initial validation step was crucial to ensure the reliability of the data acquired through the O.B.D-2 interface. Vehicle speed and engine speed values obtained via the ELM327 adapter and ScanMaster software, were contemporaneously compared against the readings displayed on the vehicle's standard dashboard instrumentation (speedometer and tachometer). This comparison serves as a practical validation check, as both the O.B.D-2 system and the dashboard typically rely on the same underlying sensor data processed by the vehicle's E.C.Us. This cross-referencing yielded a high degree of concordance, with calculated precision estimated at 99.8%, confirming the suitability of the O.B.D-2 data stream for the intended analysis.

The collected time-series data for vehicle speed, engine speed, throttle position, and engine load were systematically analyzed. The primary analytical approach involved examining the interrelationships between these variables under different operational snapshots, focusing on how engine load (%) varied with changes in vehicle speed (km/h) and engine speed (RPM). Statistical methods, including regression analysis, were employed to quantify the strength and significance of the relationships between engine load, engine speed, and vehicle speed, providing a robust assessment of their interdependence. Correlation analysis was also used to evaluate the relationship between a derived work coefficient (Engine Speed/Engine Load) and measured fuel consumption. Graphical representation of these correlations is provided to visualize and interpret the findings of this work.

3. Results and Discussion

In our experiment, the average speed for vehicle 1 was 41.5 km/h. The engine loads ranged from 17.25% to 92.94%, which is the point that the vehicles are at medium to high RPM and the most torque is needed. The average throttle position was 20.5%. In order to determine the impact of engine load, vehicle speed, and engine speed on fuel consumption, we included the fuel consumption rate as a variable in our analysis. All values are summarized at table 1 while the five individual frames are illustrated at Figure 8 below.

Table 1 Vehicle 1 real time data

Engine Runtime	Vehicle Speed (km/h)	Engine Speed (RPM)	Throttle Position (%)	Engine Load (%)
3:47:15	42.27	2382	34.12	92.94
3:47:58	62.21	1353	16.47	30.3
3:48:48	59.89	2060	21.18	42.35
3:49:45	87.02	1828.75	15.29	20.39
3:50:09	100.85	2052.25	15.69	18.82

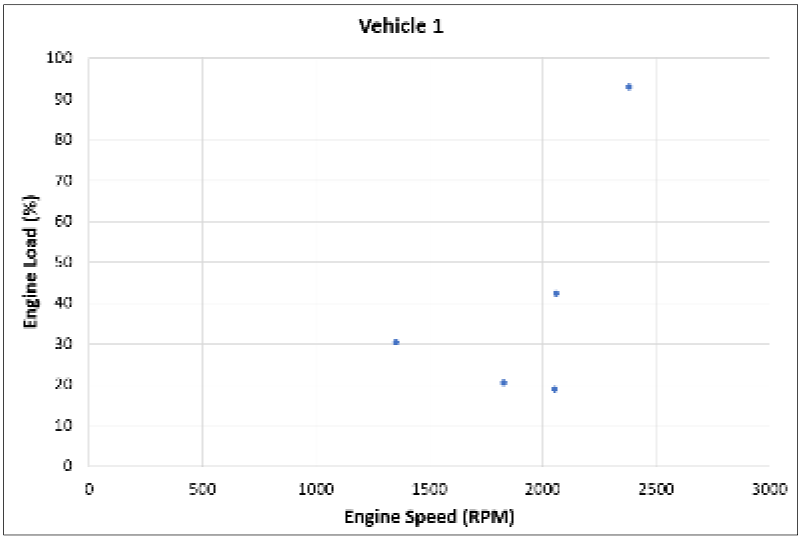


Figure 8 Testing values correlation for vehicle 1

According to the real time data of table 1, while the vehicle is moving at a low speed (42.27 km/h) with engine speed over 2000 rpm (2382 rpm) and throttle position at 34.12%, the engine load reaches 92.93%. With the throttle setting allowing a little fraction of the incoming air to pass, the engine load dramatically lowers with increased vehicle speed

(62.21 km/h) while the engine speed drops (1353 rpm). We find that when we have a relatively high speed with engine speed below 2000 rpm (1828.75 rpm) the throttle position open at 15.29% plus the engine load is at 20.39%. In contrast, the engine load decreases significantly as the speed increases (59.89 and 100.85 km/h) and the engine speed increases (2060 and 2052.25 rpm) which exceed 2000 rpm, shown in Figure 9. Thus, the engine load decreases as the vehicle speed and engine speed rise, but it climbs noticeably when the vehicle speed and engine speed fall.

Table 2 Vehicle 2 real time data

Engine Runtime	Vehicle Speed (km/h)	Engine Speed (RPM)	Throttle Position (%)	Engine Load (%)
5:00:01	0	1022.5	16.47	19.22
5:02:44	32	1487.5	20.39	33.33
5:08:30	40	1930.25	20.78	34.12
5:09:05	25	1300.75	21.96	17.25
5:18:52	11	719.5	16.08	33.33

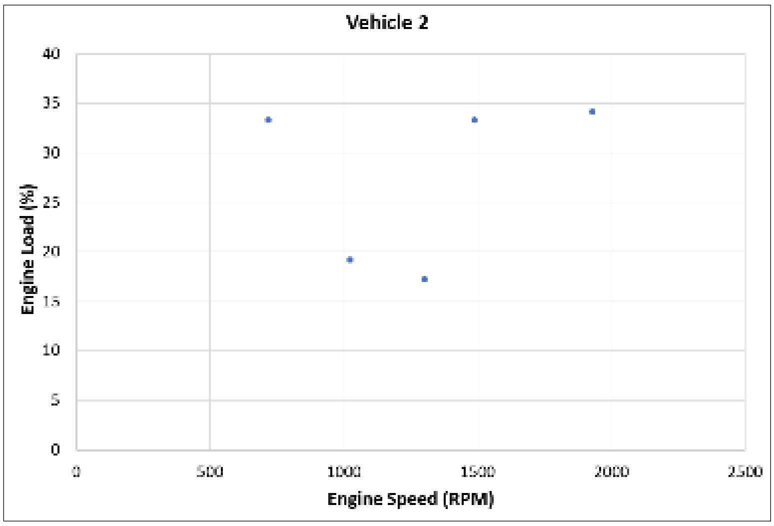


Figure 9 Testing values correlation for vehicle 2

Table 2 indicates that, despite the vehicle being stationary at traffic lights, engine load is at 14% and it increases to 19.22% when the engine speed exceeds of 1000 rpm. Engine load reaches a value of 33.33% with vehicle speed exceeding 32 km/h and engine rotation speed over 1000 rpm. However, this increase in load is minimal as the vehicle speed increases further to 40 km/h and engine rotates at 2000 rpm. The engine load experiences a substantial reduction, 17.25%, as the vehicle speed falls to 25 km/h, with the engine speed remaining above the 1000 rpm limit. The system exhibits an increase in load, reaching 33,33% when the rounds per minute fall below the 1000 limit, and the vehicle speed decreases by 11 km/h.

Table 3 Vehicle 3 real time data

Engine Runtime	Vehicle Speed (km/h)	Engine Speed (RPM)	Fuel Consumption (lt/100km)	Engine Load (%)
3:52:40	20	2694.8	6.1219	61.96
4:02:10	38	1742.8	1.9689	17.65
8:35:06	43	3058.3	12.5226	57.65
8:49:07	55	2535.5	2.9917	43.53
9:09:03	6	869.3	0.3344	40.39

Finally, the frames showing the five distinct condition values are portrayed in Figure 10.

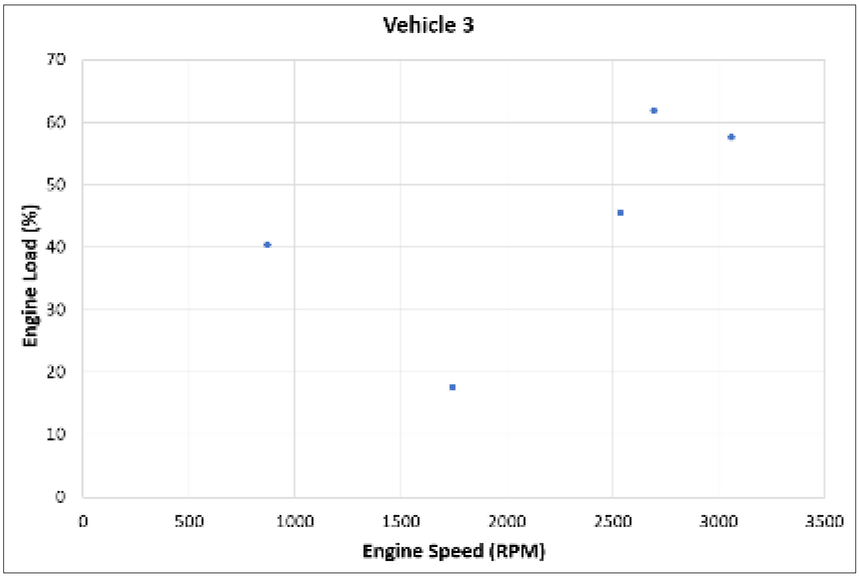


Figure 10 Testing values correlation for vehicle 3

The observed data in Table 3 demonstrates a notable increase in engine load at 61.96%, when the vehicle speed is at a moderate level while the engine speed exceeds the 2500 rpm optimum range limit. The engine load decreases significantly to 17.65% as the vehicle speed increases, reaching a low point at a rate of 38 km/h. At this point, the engine speed drop to 1742.8 rpm. Engine load rises at 57.65% while the vehicle accelerates, reaching a speed of 43 km/h when the engine rotational speed exceeds 3000 rpm (3058.3 rpm). At a reduced RPM of less than 3000 (2535.5 rpm) the engine load diminishes as the vehicle speed reaches 55 km/h, but remains elevated to a level of (43.53%). The engine load remains consistent with previous measurements (40.39%) when the vehicle speed decreases significantly (6 km/h) and its engine speed falls below the threshold of 1000 rpm (869.3 rpm).

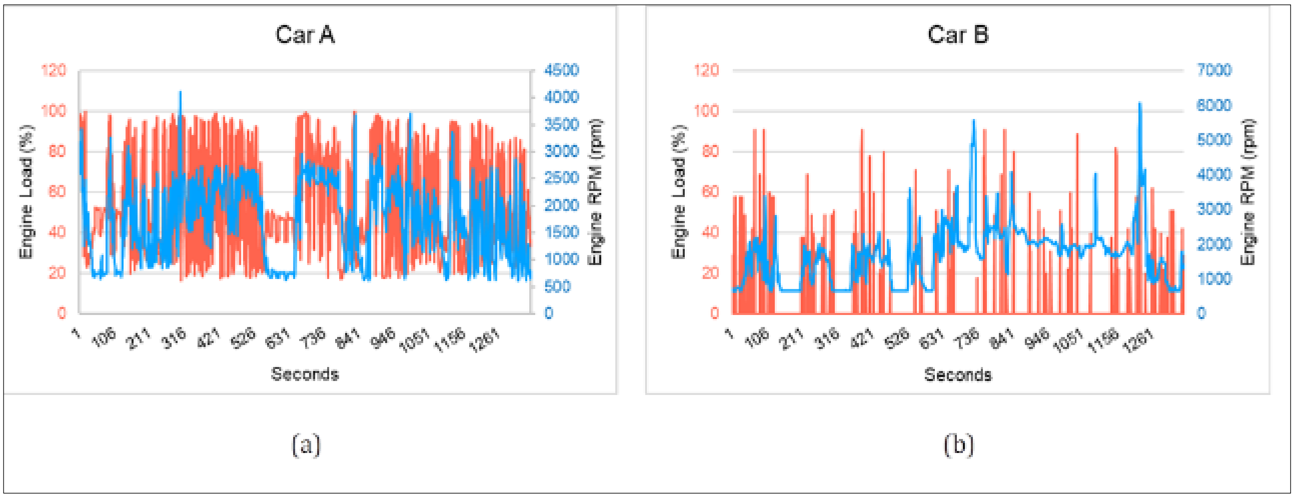


Figure 11 Time series of each car in relation to the engine speed (RPM) and the engine load (%), over a period of 1400 seconds. (a) Car A engine speed and the engine load, (b) Car B engine speed and the engine load

For research purposes, a statistical analysis of the data is performed. This analysis includes measurements from two vehicles, where 1400 measurements have been collected for each vehicle. These measurements include a 1second time frame, while the total duration of the experiment, for each vehicle, is twenty minutes. In statistical modeling, regression analysis is used to estimate the relationships between two or more variables. In this case of analysis, the dependent variable and the independent variable or independent variables are included. Dependent variable (as a criterion variable) is the main factor to be investigated, while independent variables (explanatory variables, or predictors) are the factors that could influence the dependent variable.

The goal of regression analysis is to understand how the dependent variable changes when one of the independent variables changes, and allows for a mathematical way to determine which of these variables actually have an impact. Data from two cars only (Car A, Car B) are presented for statistical analysis as more data is available. The data collected from each car are, vehicle speed (km/h), engine speed (RPM), engine load (%). Figure 11 shows the time series of each car in relation to the engine speed and the engine load, over a period of 1400 seconds.

The statistical analysis of the data for each car is then presented. In particular, the significance of each variable, such as engine load, engine speed, engine speed in relation to the speed of the vehicle is studied. In this way the influence of the variables on the final result is revealed. The significance index has been set as $\alpha = 0.05$. Table 4 shows the data of the statistical analysis.

Table 4 Statistical analysis data of each car

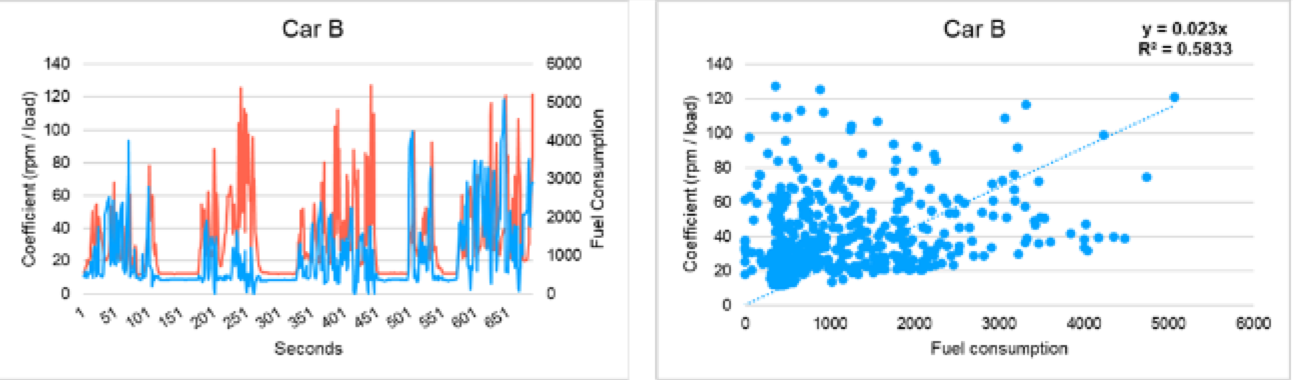
Regression Statistics	**Car A**	**Car B**
Multiple R	0.618	0.786
R Square	0.382	0.618
Adjusted R Square	0.381	0.617
Standard Error	29.237	19.065
Observations	1356	1369
Significance F	$6.2 \cdot 10^{-142}$	$7.4 \cdot 10^{-286}$
p-value	**Car A**	**Car B**
Intercept	$4.49 \cdot 10^{-9}$	$618 \cdot 10^{-6}$
Engine Speed (RPM)	$4.8 \cdot 10^{-143}$	$2.3 \cdot 10^{-287}$
Engine Load (%)	$4.53 \cdot 10^{-59}$	$5.8 \cdot 10^{-40}$

According to the results of the statistical analysis it follows that, there is a direct link between the engine load and the rotation of the motor and all this has an effect on the speed of the vehicle. This is explained as the significance F in both cases present a very low value, which means that, statistically, the null hypothesis (that they are not related) is in the rejection region, which is not valid. Since the variables are related, the next question answered by Table 1, is how much each variable contributes to the final result. This answer is given through the p-value values of each variable. According to Table 1 it is observed that the engine rotation (rpm) shows a higher participation as they have an extremely low p-value, while the engine load also participates as it also has a low p-value. from the statistical analysis it is concluded that there is a direct link between the above-mentioned variables in the final result, which is confirmed by the experiment.

To evaluate the experiment of this work, the correlation of fuel consumption in relation to engine rpm and engine load was further studied. The evaluation procedure was carried out for one vehicle (Car B) as all three vehicles show similar results. Dividing the engine speed by the engine load gives a coefficient which represents the work required for the speed of the vehicle. This coefficient was correlated with fuel consumption and the results of the time series and scatter plot of these data are shown in Figure 12.

From Figure 10 it can be concluded that, the work coefficient calculated from the equation Engine Speed/Engine Load, is consistent with the fuel consumption according to the time series. The scatter plot shows that the correlation is confirmed as the degree of determination between the work coefficient and fuel consumption shows a value $R^2 = 0.58$. According to the results of this evaluation, both the calculation of the work factor and the fact that the fuel consumption is proportional to the work factor are confirmed.

We draw the conclusion that an increase in vehicle speed has a significant impact on engine load based on the data displayed in the tables and graphs. It is noted that there is minimum engine load adjustment when the vehicle speed rises and their engine speed rises above 1500 rpm. However, when the cars slow down and the rpm drops below 1500 rpm, the engine load does not rise significantly. Conversely, when the vehicle is moving at a low speed and the engine speed is higher than 1500 rpm, an increase in engine load is noticed. The confirmation of the above is shown through the statistical analysis carried out during the experiment. Through this analysis it is clear that there is a direct link between vehicle speed and engine load and engine speed. Furthermore, the direct relationship of both engine load and engine speed to vehicle speed is confirmed as shown by the very low p-value values of these variables.



(a) (b)

Figure 12 Coefficient work of engine speed/load and fuel consumption values for car B: (a) Time series for the 3-values coefficient work, (b) Scatter plot and determination degree (R^2)

The measurements we collected with the O.B.D-2 system cannot be considered fully accurate because of the time frame. One of the shortcomings of O.B.D-2 is its inability to continuously record data that offers a more accurate representation of the vehicle true state. O.B.D-3 protocol will provide a solution for this problem. The implementation of O.B.D-3, a real-time vehicle emissions monitoring system will warn drivers of hazardous emissions while they are driving [29-30]. Satellite communications will be used to transmit the information to the administrative department at high speeds, as a result, the achievement of elimination of data transmission delay, the minimizing delay of fault detection, and immediate repair. O.B.D-3 implementation requires continuous communication technology, standards, and regulations. It also requires accurate and reliable diagnostic functions. Nowadays, O.B.D-3 is still in the primary stage while remote diagnostic and maintenance technology will be the focus of the O.B.D-3s development path.

The 3rd generation of the O.B.D protocol will introduce high speeds in data transportation and will bring changes to the priority categorization of CAN-Bus as a result of eliminating data transmission delay [30]. Information should be delivered to the administrative department on a timely basis via satellite communications. The management department will require drivers to conduct inspections and maintenance at the nearest repair shop, and the stored data will be stored to determine if the problem has been resolved at the next vehicle inspection and maintenance [31]. Furthermore, the administrative department of in-use vehicle can identify and organize the same emission problems in order to assess whether the most rigorous emissions recall should be carried out. The O.B.D-3 technology keeps vehicle exhaust emissions within the normal range at all times and streamlines the time-consuming testing procedure of in-service cars to better gather automotive maintenance and application information [32]. Since the information will be transmitted via satellite communications at high speeds to the administrative department, the delay between the detection of an emissions fault malfunction and vehicle repair will be minimized, down to 50ms at most. It will also be possible to wirelessly manage the vehicle and constantly record all parameters, such as errors, pollutant rates, unlocking of doors, excessive speed, etc., in a built-in memory [33].

More specifically, O.B.D-3 will include a radio transponder for every vehicle. Using this transponder, the Vehicle Identification Number (V.I.N) and the Diagnostic Trouble Codes can be sent to the user or the manufacturer for necessary checks using the cloud connectivity [34]. In this direction, the German vehicle industries have already started making significant progress. In general, a vehicle installed with the O.B.D-3 protocol must be able to report emissions problems directly to regulatory authorities. As soon as the M.I.L light illuminates, the module is able to make a report of emission issues via satellite communication achieving high efficiency and cost savings of the system. It is reasonable to say that the implementation of the O.B.D-3 protocol will likely be the largest change in the automotive industry since the creation of modern cars [35-36].

4. Conclusion

This research provides an in-depth analysis of the effectiveness of the O.B.D-2 protocol in monitoring engine load and vehicle performance across varying driving conditions. The results from our experimentation revealed that engine load fluctuates significantly based on vehicle speed, engine speed, and throttle position. Specifically, engine load peaked at 92.94% when the Vehicle 1 was moving at 42.27 km/h with an engine speed of 2382 rpm and a throttle position of 34.12%. However, as the vehicle speed increased to 62.21 km/h and engine speed dropped to 1353 rpm, engine load significantly decreased to 30.3%, indicating reduced engine stress.

For Vehicle 2, engine load was observed to be highest (33.33%) at speeds above 32 km/h and engine speed exceeding 1000 rpm, but when the vehicle speed dropped to 25 km/h with an engine speed above 1000 rpm, the engine load decreased to 17.25%. Similarly, for Vehicle 3, the highest engine load recorded was 61.96% at 20 km/h with an engine speed of 2694.8 rpm, while it dropped to 17.65% when the vehicle speed increased to 38 km/h and engine speed decreased to 1742.8 rpm. These observations suggest that engine load is highest at low speeds with high RPM and decreases as vehicle speed increases and engine speed stabilizes beyond 1500 rpm.

For research purpose and to confirm the results, a statistical analysis of the vehicle speed, engine load and engine speed data was performed. The statistical results for both vehicles showed, very low significance F, which means that there is a high degree of correlation between them, while the low p-value values of each variable showed the influence on the final result.

This research thoroughly analyzed the effectiveness of the O.B.D-2 protocol for monitoring vehicle engine load and performance under diverse driving conditions. The experimental results clearly demonstrated that engine load is significantly influenced by vehicle speed, engine speed, and throttle position. While O.B.D-2 provides valuable real-time diagnostic data, a notable limitation is its inability to continuously record comprehensive data, hindering a fully accurate representation of the vehicle's state over time. The upcoming O.B.D-3 protocol aims to overcome these shortcomings. O.B.D-3 promises real-time emissions monitoring and remote diagnostics, potentially utilizing satellite communications for high-speed data transmission to administrative departments This would minimize delays in fault detection and repair. O.B.D-3 is expected to include features like radio transponders for sending Vehicle Identification Numbers (V.I.N) and Diagnostic Trouble Codes (D.T.C) directly to regulatory authorities or users via cloud connectivity. It could enable constant recording of parameters and wireless vehicle management. The transition to O.B.D-3 represents a potentially transformative advancement in automotive technology, set to revolutionize vehicle diagnostics, emissions management, maintenance efficiency, and overall performance monitoring.

In summary, this study underscores the utility of O.B.D-2 for monitoring engine load and highlights the importance of optimizing driving behavior for fuel efficiency. While O.B.D-2 has shown potential, the forthcoming O.B.D-3 standard is poised to significantly enhance real-time monitoring and diagnostic capabilities. Future research efforts should concentrate on refining O.B.D-3 standards, ensuring its seamless integration with evolving automotive technologies, and exploring its broader applications for improving vehicle sustainability and efficiency.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflicts of interest.

Statement of informed consent

Informed Consent Statement not applicable.

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