EFFECTS OF DRIVING STYLES ON VEHICLE PERFORMANCE, FUEL CONSUMPTION AND ENGINE EMISSIONS

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ABSTRACT*:*Fuel consumption and emission rates are often determined under standardized laboratory test conditions to ensure comparability between vehicles. While these tests provide a useful benchmark, they do not fully reflect the complexities of actual driving environments. In real-world operation, vehicles are exposed to a wide range of conditions that differ significantly from those in controlled testing. As a result, there is a gap between real-world fuel consumption and the reported fuel consumption and emission rates. This paper studied the effect of driving styles including aggressive driving, unnecessary idling, and vehicle operating mass on vehicle performance, fuel consumption and emission rates for light duty vehicles. In order to investigate the effect of these different driving styles on the vehicle performance in a quantitative way, a detailed dataset and real-time measurement including instantaneous speed, acceleration, fuel consumption, oxygen content of the intake air, intake air temperature, and engine emission rates have been collected while driving a vehicle instrumented with vehicle data logger and on-board diagnostic scanner. The results showed that aggressive driving reduced the fuel efficiency by approximately 19% and consequently increased CO_2 emissions by 40%. Vehicle operating mass increased CO_2 emissions by 20% for an additional 100 kg. Idling condition produced hazardous emissions especially while warming up the engine. The findings highlight how informed driving habits can significantly contribute to reducing fuel consumption and lowering emissions.

KEYWORDS*: Vehicle Performance; Driving Styles; Fuel Efficiency*

1.0 BACKGROUND STUDY

Internal combustion engines are considered one of the largest greenhouse gas sources and several hazardous emissions such as nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), and particulate matters (PM). More than 14% of the 2020 total greenhouse gas emissions are from transportation sectors and 70% of the EU's CO_2 comes from the passengers' vehicles [1-2]. Numerous factors affect the fuel efficiency negatively and increase emission rate sharply. In addition to the extra cost that the vehicle driver will bear, the increase in emissions will have a severe impact and catastrophic consequences on the environment and public health.

Therefore, there is an urgent need to investigate the effect of different driving styles and other factors on the fuel efficiency and define the best driving behavior which causes the greatest increase in fuel efficiency and lowest emissions ever. The purpose of this study is to investigate the effect of different driving styles which are aggressive driving, unnecessary idling, and vehicle operating mass on the vehicle performance, fuel consumption and engine emissions.

There is a clear divergence or gap between the officially reported and the real-world fuel consumption while driving the vehicle [2]. Improper driving styles such as aggressive driving, unnecessary idling, and vehicle operating mass, lead to increase the amount of fuel consumed and consequently release more hazardous emissions including NO_x, CO, CO_2, and PM. Driving styles can be defined as the personal driving style, such as instantaneous velocities, acceleration, deceleration, and gears choice. Apart from that, driving styles differ from driver to another as it basically depends on the emotional and physical conditions of the driver and his character as well [3].

Aggressive driving can be defined as the driving style which is characterized by high acceleration, deceleration, and intense braking. The aggressive driving increases the amount of fuel consumed and CO_2 emissions dramatically, and if the driver drives his car perfectly, the amount of fuel consumed will decrease significantly [2]. One study found that aggressive driving increases the amount of fuel consumed dramatically by 26%. The amount of fuel consumed can be reduced by 17 - 26% if the drivers drive perfectly [4-6].

Vehicle idling is considered as one of the conditions that affect fuel efficiency and emissions significantly. We can define the vehicle idling as a process that occurs when the engine is running, but the vehicle itself is not moving. Idle operation leads to waste a large amount of fuel, and high emissions formation, as well as fuel residue in the exhaust. It was reported that the idle overnight trucks waste more than 800 million gallons of diesel fuel per year [7-8] .

Each liter of gasoline, a vehicle emits around 2.3 kg of CO_2, while for each liter of diesel, the vehicle emits around 2.7 kg of CO_2 [9]. While idling, the vehicle uses a highly rich air-fuel mixture and the engine is not running at peak temperature, thus, this leads to the incomplete combustion occurs, fuel residue in the exhaust, and more pollutants such as PM, hydrocarbon (HC), NO_x, CO, volatile organic compounds, and CO_2. Idling time should not exceed 30 seconds, and in this case, there is a potential for large reductions in emissions [10-11].

The operating mass of a vehicle includes the mass of the vehicle itself, the fuel in the tank, the passengers and other equipment. Admittedly the power is directly proportional to the load, and more power leads to increased fuel consumption. In addition, the extra mass increases the rolling resistance and leads to a non-consistent distribution of the vehicle mass in contrast to what should be, so that leads to an increase in the amount of fuel consumed [12-13]. It is reported that an extra 100 kg leads to increased fuel consumption by approximately 5 - 7% [2].

Ultimately, considering the amount of fuel consumed and engine emissions as fixed parameters is a serious mistake which leads to overlooking several factors affecting them significantly. Despite the importance of this point, there are less research focused on it and produced a specific relationship between the driving style and fuel efficiency, most of the literature have focused on the vehicle type and fuel quality as the causes of the total fuel consumption and emissions. This study aims to investigate the effect of driving styles on vehicle performance, fuel efficiency and engine emissions.

2.0 METHODOLOGY

In order to investigate the relationships between driving styles and engine performance, fuel consumption and engine emissions, an instrumented PERODUA Myvi car has been used with the following specifications:

- Engine: 1.3 L.
- Transmission: 4 speeds manual.
- Wheelbase: 2440 mm
- Kerb-weight: 980 kg.

To quantitatively assess the impact of various driving styles on vehicle performance under actual driving conditions, the study utilised an approach involving the collection of high-frequency, real-time data. This dataset comprised detailed measurements such as instantaneous vehicle speed, acceleration, fuel consumption rates, intake air oxygen content, intake air temperature, and engine emission outputs. All measurements were gathered during on-road testing with a vehicle outfitted with a data acquisition system, which included a vehicle data logger, an onboard diagnostic (OBD-II) scanner, and a portable emission analyser. Figure 1 shows the equipment, enabling precise and reliable monitoring of all relevant parameters throughout the study.

(a) (b) (c)

Figure 1: Equipment: (a) vehicle data logger, (b) OBD-II scanner, (c) emission analyzer

2.1 Aggressive Driving Test Procedure

Rapid acceleration, frequent aggressive braking, and sudden deceleration are aspects of aggressive driving [2]. To investigate the relationship between aggressive driving in terms of high acceleration and vehicle performance, and express it in a quantitative way versus two different accelerations a_1 and a_2, the required data including (instantaneous fuel consumption (km/l), instantaneous speed, intake air temperature (°C), CO_2, and oxygen content of the intake air) has been collected during the trip by accelerating the car in the shortest time possible, then decelerating till a stop. By obtaining the speed at the particular time, then we could calculate the acceleration at each measurement point using the following formula:.

$$a = \frac{v_2 - v_1}{t_2 - t_1} \quad (1)$$

Where "*a*" is the acceleration in m/s^2, and v_1 and v_2 are the speed at time t_1 and t_2, respectively. The aggressive driving results analysis will be done by graphing the emission, amount of fuel used, intake air temperature, and oxygen content of the intake air versus speed at two different acceleration levels. There are two main testing points which are:

- 0.7 m/s^2 and 1.4 m/s^2 at 5 m/s
- 0.7 m/s^2 and 1.4 m/s^2 at 8.3 m/s

2.2 Unnecessary Idling Procedure

The main objective of this test is to illustrate the effect of idling (5 minutes) at two different conditions including (cold starting at early morning and traffic idling) on the fuel efficiency and other parameters which lead to increase the rate of emissions such as intake air temperature, oxygen content of the intake air, *etc*.

By starting the vehicle early in the morning and keeping the engine on idling mode for 5 minutes then we collect the required data during the idling duration. According to the traffic idling test, we keep driving the vehicle for 5 kilometers then stop and keep the engine on idling mode for 5 minutes as well. The tests were conducted according to the following conditions:

i. Cold starting: The test was conducted on May 11 at 6:30 am, and the air temperature at that time was 20-23 °C.
ii. Traffic idling: The test was conducted on May 4 at 4:30 pm, and the air temperature at that time was 31-33 °C.

2.3 Vehicle Operating Mass Procedure

The main objective of this test is to illustrate the effect of high operating mass on the fuel efficiency and emissions rate. In order to assess the effect of vehicle mass on the vehicle performance, some important data has been collected by following the steps below.

i. Driving the vehicle with an additional weight equal to 0 kg and collecting all the required data.
ii. The test was then repeated four times, each time increasing the load by an additional 50 kg, resulting in total added masses of 50 kg, 100 kg, 150 kg, and 200 kg. The additional weight was placed securely inside the vehicle to ensure consistent load distribution. All tests were conducted over the same distance of 2.8 km at approximately the same average speed of 35 km/h to minimize variability in driving conditions.

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3.0 RESULTS AND ANALYSIS

In order to investigate and assess the effect of driving styles including aggressive driving, unnecessary idling, and vehicle operating mass on vehicle performance, fuel consumption and engine emissions, all the required data has been collected and presented in tables and charts as shown below. High fuel efficiency with lower exhaust emissions basically relies on the intake air temperature as well as oxygen content of the intake air because higher oxygen concentration helps in improving combustion process and fuel burning rate [11]. So, we focused on the effect of driving styles on these two variables for a deeper and more accurate analysis.

3.1 Effect of Aggressive Driving on Vehicle Performance

First of all, all tests were conducted under similar conditions, on the same road, and by the same driver in order to reduce the effect of any other variables such as weather-related variables, roadway-related variables, and the driver related variables on the results as much as possible. All the required data has been collected at two different acceleration levels at the same speed as shown in the figures below to illustrate the effect of aggressive diving in terms of high acceleration on vehicle performance regardless of the vehicle speed.

Overall, at the same speed the values of CO_2, and intake air temperature are higher at higher acceleration level and vice versa. Whereas the oxygen content of the intake air and instantaneous fuel consumption decreases by increasing the acceleration. In terms of instantaneous fuel consumption, instantaneous fuel consumption refers to how far the vehicle can travel per each liter of fuel consumed based on the vehicle consumption at that specific moment. From Figure 2 it is clear that the fuel efficiency in terms of instant fuel consumption (km/l) is inversely proportional to the acceleration level. At the same speed (5 m/s) the instant fuel consumption is equal to approximately 17.6 km/l at 0.7 m/s^2. While at 1.4 m/s^2 the value of instant fuel consumption decreased to 16 km/l. Similarly at v = 8.3 m/s the instant fuel consumed declined from 14.26 to 12 km/l (at 0.7 m/s^2 and 1.4 m/s^2 respectively).

Secondly, from Figure 3 it shows that the acceleration value is directly proportional to the amount of CO_2 emitted at the same speed. The amount of CO_2 emission experienced a sharp increase from 158.32 g/km to appoximately 225 g/km at the same speed (at 0.7 m/s^2 and 1.4 m/s^2 respectively). Similarly, CO_2 emission shows a climb from 283 g/km to approximately 412 g/km at the same speed (at 0.7 m/s2 and 1.4 m/s^2 respectively).

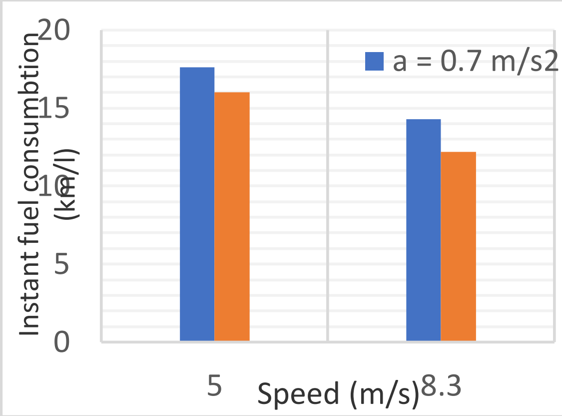

Figure 2: Effect of acceleration on fuel efficiency

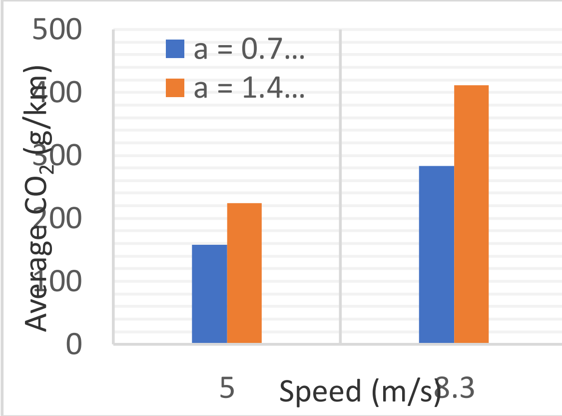

Figure 3: Effect of acceleration on CO_2 emissions.

Figure 4 shows that intake air temperature is directly proportional to acceleration level. The intake air temperature is colder at lower acceleration at the same speed and vice versa. At 5 m/s speed, the temperature increased from 73 °C up to 76 °C (at 0.7 m/s^2 and 1.4 m/s^2 respectively). Similarly, at 8.3 m/s speed, the temperature witnessed a climb from 77.5 °C to 79.5 °C (at 0.7 m/s^2 and 1.4 m/s^2 respectively). The rise in intake air temperature at higher speeds can be attributed to the fact that heat generation from the engine and cooling system increases more rapidly than the cooling effect of ambient airflow, causing the intake air to absorb more heat before entering the cylinders.

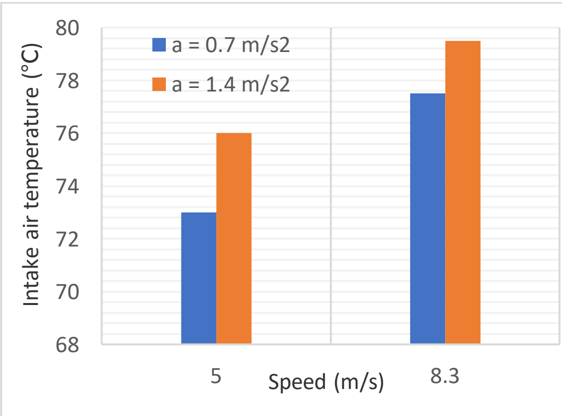

Figure 4: Effect of acceleration on the intake air temperature

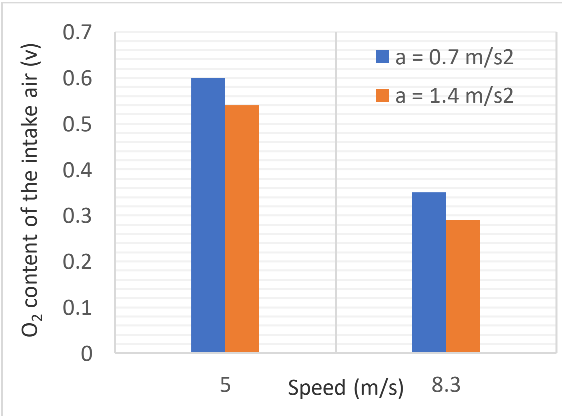

Figure 5: Effect of acceleration on oxygen content of the intake air

As discussed earlier, there is a high correlation between intake air temperature, oxygen content of the intake air, engine performance, specific fuel consumption, as well as engine emissions. The characteristics of emissions and combustion are basically relying on the oxygen enrichment in the intake air, and higher oxygen concentration in the combustion chamber causes complete combustion, higher combustion stability, and oxidation of hydrocarbons as well as CO emissions [14]. Figure 5 shows the oxygen enrichment in the intake air at two different accelerations 0.7 m/s^2 and 1.4 m/s^2 at two different speeds. It can be inferred that lower intake air temperature leads to high availability of oxygen in the combustion chamber and consequently give rise to combustion stability and combustion efficiency which in turn reduce the amounts of emissions emitted.

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3.2 Effect of Unnecessary Idling on Vehicle Performance

Table 1 illustrates the effect of unnecessary idling on vehicle performance in terms of (amount of fuel consumed, CO_2 emission, temperature of the intake air, and the concentration of oxygen in the combustion chamber) at two different kinds of idling conditions including cold starting and traffic idling.

Overall, the amount of fuel used is higher in traffic idling conditions as the intake air temperature is higher which consequently leads to decrease the concentration of oxygen which causes lower combustion stability and incomplete combustion. There is no significant change in the amount of CO_2 emitted in both tests. In terms of amount of fuel used, traffic idling for five minutes required 0.12 liters of fuel, while in cold starting test it consumed 0.06 liters for the same period, however in cold starting test a higher amount of CO_2 emitted compared to traffic idling test (250.5 g/km and 230.3 g/km respectively). The intake air temperature at traffic idling is higher as opposed to cold starting test (55 °C and 32 °C respectively). As mentioned earlier the cold air is denser which promotes a higher concentration of oxygen. It can be derived that unnecessary idling wastes the fuel and produces dangerous emissions especially while warming up the engine "cold starting" which often happens as a result of cold catalytic converter.

Table 1. Traffic idling and cold start idling results

	Traffic idling	Cold starting
Fuel used (*l*)	0.12	0.06
Intake air Temperature (°C)	55	32
CO_2 (*g/km*)	230.3	250.5
Oxygen content of the intake air (*volts*)	0.33	0.52

The data in Table 2 has been collected by using automobile gas analyser for the purpose of investigating the effect of unnecessary idling - like waiting on the side of the road or in traffic jams. It shows that the concentration of carbon dioxide (CO_2) emitted from the tailpipe reached 15.15 %. The oxygen (O_2) content recorded was low at 0.11 %, which reflects limited air intake and incomplete combustion processes typical of idling conditions. Hydrocarbons (HC), measured at 50 parts per million (ppm), indicate the presence of unburnt fuel. Carbon monoxide (CO) concentration was 0.02%, signifying the release of another hazardous emission.

Table 2. Traffic idling emissions

Tailpipe emissions	Traffic Idling Test
CO_2 (%)	15.15
O_2 (%)	0.11
HC ppm	50
CO (%)	0.02
Air fuel ratio	14.57

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3.3 Effect of Vehicle Operating Mass on Vehicle Performance

The tests have been conducted at the same time, driving at approximately the same speed (35 km/h), same road condition, and approximately same ambient temperature (30-34 °C). These parameters have been fixed to reduce their potential impact on the results as much as possible.

Table 3 lists the results of different vehicle operating mass by travelling with extra 50 kg, 100 kg, 150 kg, and 200 kg on several parameters. Overall, the vehicle operating mass is inversely proportional to the fuel efficiency (km/l) and the oxygen availability in the intake air. The intake air temperature and CO_2 increase by increasing the vehicle mass and vice versa.

Table 3. Vehicle operating mass test results

Additional mass (kg)	Fuel efficiency (km/l)	Average CO_2 (g/km)	O_2 concentration (v)	Intake air Temperature (°C)
0	19.58	315	0.6	38.59
50	15.27	328.53	0.42	60.4
100	11.68	378.82	0.34	69
150	9.69	414.56	0.29	70.3
200	7.97	553.2	0.28	75.9

Figure 6 illustrates the effect of additional mass on fuel efficiency in terms of vehicle kilometers travelled per each liter of fuel. What stands out from the graph is that the fuel efficiency is inversely proportional to the vehicle mass. In terms of CO_2 emissions (Figure 7), an additional 50 kg to the vehicle mass causes a slight increase in the amount of CO_2 emitted whereas the trend increased more sharply by adding extra weight. The first extra 50 kg led to an increase in amount of CO_2 from 315 g/km to 328.53 g/km, while by adding additional 100 kg, 150 kg, and 200 kg the amount of CO_2 witnessed a climb to 378.82 g/km, 414.56 g/km, and 553.2 g/km. Finally, it can be noted that the vehicle's mass increases the amount of CO_2 emitted by 20 % for an additional 100 kg while the percentage increases dramatically up to approximately 46 % for another extra 100 kg.

The presented graphs in Figure 8 and Figure 9 show the effect of additional mass on the intake air temperature as well as the oxygen concentration in the intake air. As mentioned earlier in Section 3.1, the amount of exhaust emission and fuel efficiency greatly rely on the intake air temperature and the oxygen availability in the combustion chamber. It is obvious that the colder the intake air the higher concentration of oxygen due to the fact that cold air is denser and consequently it contains a higher value of oxygen. The intake air temperature increased dramatically from 38.59 °C to approximately 61 °C then up to 69 °C for additional 50 kg and 100 kg respectively, afterwards the trend witnessed a slight increase up to 70.3 °C then 75.9 °C for additional 150 kg and 200 kg, respectively.

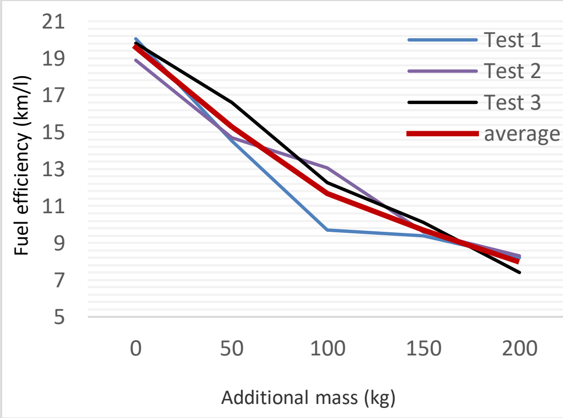

Figure 6: Effect of vehicle operating mass on fuel efficiency

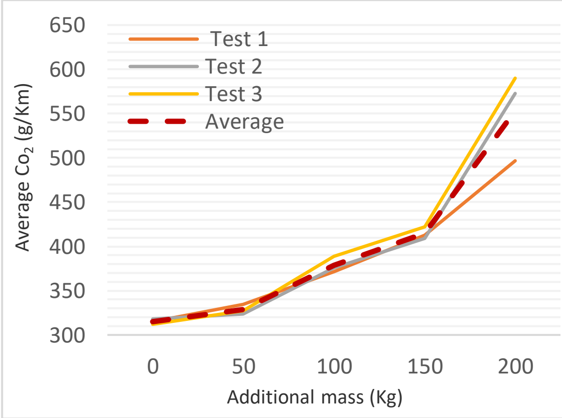

Figure 7: Effect of vehicle operating mass on average CO_2

On the effects of vehicle mass to the oxygen concentration in the intake air and in the combustion chamber, the trend witnessed a sharp decrease in the beginning as the oxygen concentration reduced from 0.6 v to 0.42 v then reduced to 0.34 v for additional 50 kg and 100 kg, respectively. Afterwards the oxygen concentration has not witnessed a significant change. Overall, the trend of oxygen concentration decreases versus the additional mass.

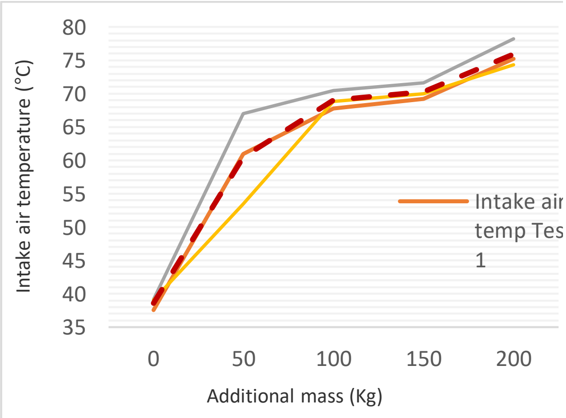

Figure 8: Effect of vehicle operating mass on intake air temperature

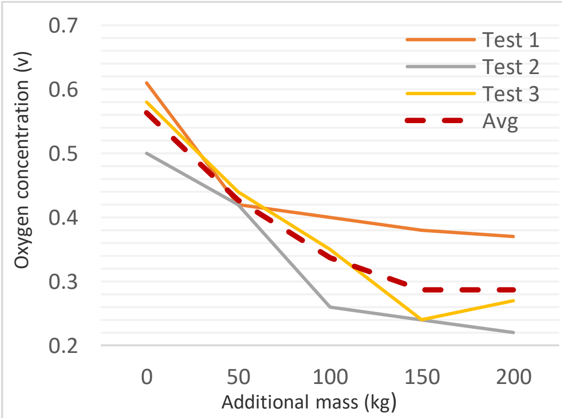

Figure 9: Effect of vehicle operating mass on oxygen concentration

4.0 CONCLUSION

The influence of driving styles, idling, and vehicle operating mass on vehicle performance, fuel consumption, and engine emissions was examined in this study. Improved combustion efficiency and reduced emissions were facilitated by lower acceleration levels. In contrast, aggressive driving and increased vehicle mass were found to negatively affect fuel efficiency and increase emissions. For future work, a multi-vehicle, multi-environment study is recommended, incorporating standardised automotive testing protocols to ensure data comparability. This would enable the development of robust models that can predict the effects of different driving styles and vehicle configurations across a range of conditions.

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