IJSRA

International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

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Estimating the vehicle-specific power difference between actual driving data and world motorcycle test cycle: a case study for motorcycles in Hanoi

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International Journal of Science and Research Archive, 2025, 15(02), 1269-1274

Publication history: Received on 11 April 2025; revised on 22 May 2025; accepted on 25 May 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.2.1519

Abstract

Comprehending real-world driving characteristics is crucial in transportation engineering and vehicle emission modeling. Standard test cycles often fail to capture the dynamic and diverse nature of on-road driving behavior. This study assessed the disparity in vehicle-specific power (VSP) between the actual driving data of the test motorcycle (MC) in Hanoi and the World Motorcycle Test Cycle (WMTC). The real-world driving data of MC in Hanoi was collected using a GPS device with a 1Hz update rate. The gained data was preprocessed to remove random errors before using it to calculate VSP. A significant difference related to VSP was detected between the actual driving data in Hanoi and WMTC. The percentage difference for maximum/minimum/average positive VSP values, and the 95th percentile of VSP between the two datasets ranges from 112.06% to 136.74%. The concentration in the operation mode with a high emission potential of the real-world driving data is 114.5% higher than that in WMTC.

Keywords: VSP; WTMC; Driving characteristics; Motorcycle; Hanoi

1. Introduction

Rapid climate change and the depletion of fossil fuels pose a serious threat to humanity today. With a market share of around 1.21 × 105 PJ, the transport sector is currently one of the major sectors that has garnered a lot of attention due to its enormous energy consumption and its strong dependence on fossil fuels [1]. In Vietnam, about 16.5% of the total national energy consumption demand is accounted for by the total final energy consumption demand of the transport sector. As an unexpected result, greenhouse gas (GHG) emissions from the transport sector account for about 18% of the energy sector's total GHG emissions and are still on an annual increasing trend in Vietnam [2]. Therefore, it is crucial to strictly regulate fuel consumption (FC) and emissions associated with the transport industry globally, and in Vietnam specifically. It will be easier to control the vehicle's emissions if its FC characteristics and emissions are well understood.

Since the driving characteristic of the vehicle is one of the key factors influencing its emission features, it is always taken into account in all of the vehicle emission study methods. The features of the vehicle, however, differ significantly between nations and even among regions of the same nation [3, 4]. Consequently, the accuracy of the obtained emission data may be decreased if the vehicle's emissions are measured based on the test cycle used in type approval testing.

Among various parameters used to characterize vehicle operation, vehicle-specific power (VSP) has emerged as a key indicator. VSP quantifies the power demand per unit mass of a vehicle based on instant speed, acceleration, road grade, and aerodynamic resistance. Therefore, VSP directly impacts the vehicle's FC and emissions since it acts as a thorough stand-in for determining engine load [5]. Researchers can gain a better understanding of driving intensity and its effects on the environment by examining the distribution and frequency of VSP in real-world driving situations. The fact is that VSP has been utilized as an input parameter relating to the real-world driving characteristics in a lot of vehicle simulation software, such as Motor Vehicle Emission Simulator (MOVES), International Vehicle Emissions model (IVE)...

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In order to reaffirm the significance of measuring vehicle emissions using the local representative driving cycle rather than using regular test cycles in studies related to emission estimation, this study will demonstrate the remarkable difference in VSP between the real-world driving characteristics of MC in Hanoi and the World Motorcycle Test Cycle (WMTC).

2. Methodology

In order to explore the MC's VSP characteristics under real-world driving conditions, a general research framework is summarized as follows:

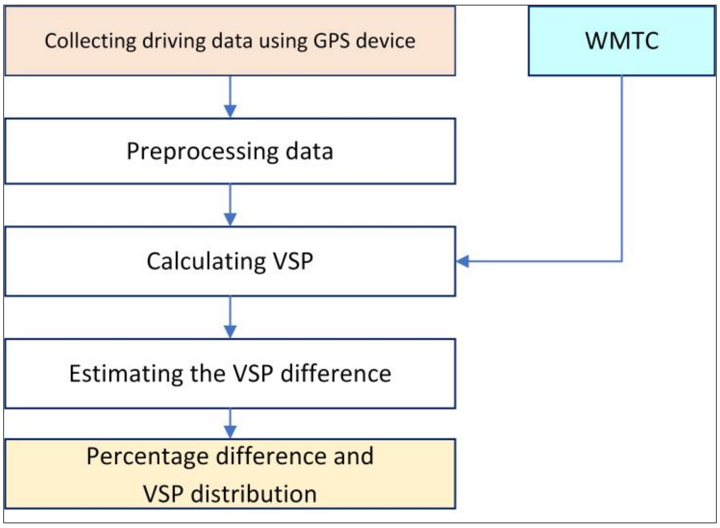

Figure 1 General research framework

The flowchart in Fig. 1 presents a systematic procedure to assess the discrepancy in VSP between real-world motorcycle driving data and the WMTC. The process begins with collecting driving data using a GPS device, followed by preprocessing to eliminate noise and errors. Subsequently, VSP values are calculated and compared with those derived from WMTC. The differences are then estimated to determine the percentage deviation and analyze the distribution of VSP values, providing insights into the representativeness of WMTC under actual driving conditions.

2.1. Collecting data

In this study, a GPS device with a 1Hz update rate was used to collect the instant speed of the test MC on five routes in the Hanoi inner city area. The on-road driving characteristics of MCs in Hanoi were recorded on both weekdays and weekends, covering off-peak and peak hours (6:30–8:30; 10:30–12:00; 16:30–19:00). To minimize the influence of driver behavior, only one driver conducted the entire real-world driving data collection.

2.2. Preprocessing data

The fact is that random errors resulting from abrupt signal loss, erroneous or outlying data points, and speed drifting may appear in the GPS data [3, 6]. Therefore, it is necessary to minimize these errors before using the GPS data for calculating VSP and its distribution in the next step. This study adopted the filter designed to process GPS data as in the study of Khanh, Yen-Lien [7]. The main steps in this filter are as follows:

- Remove duplicate records
- Replace outlying speed values
- Remove signal gaps
- Calculate instantaneous acceleration
- Repair outlying instant power values
- Denoise and smooth the instantaneous speed signals

The aforementioned data preprocessing processes are organized in ascending order of complexity to help detect and repair random errors. The built-in code in the MATLAB software will perform the processes automatically.

2.3. Calculating vehicle-specific power

The US Environmental Protection Agency (US EPA) provides the generic VSP calculation based on the following average values [8, 9]:

$$VSP = (1.1 \times acc + 9.81 \times gr + 0.132) \times v + 3.02 \times 10^{-4} \times v^3 \quad \text{..........(1)}$$

Where: v is the instant speed (m/s), acc is the instant acceleration (m/s^2), and gr is the road grade. For urban roads in Hanoi, the road grade is 0.

This study also demonstrates the difference in VSP-related operation mode distribution between the real-world driving data and WMTC. In which, the vehicle operation mode is determined according to the definition in the MOVES software (see Table 1). MOVES, developed by the US EPA, is one of the most widely used tools for estimating the energy demand and emissions from mobile sources, consisting of on-road and non-road sources. MOVES is especially useful for assessing the environmental effects of new energy vehicles (NEVs) and assisting with long-term transportation planning that aligns with decarbonization objectives because of its capabilities.

Table 1 Specifies operational modes in MOVEs based on speed and VSP [10]

opMode ID	Vehicle operation	Range of VSP and speed
1	Idling	
11	Low Speed Coasting	VSP< 0; 1 ≤ Speed<25
12	Cruise/Acceleration	0 ≤ VSP< 3; 1 ≤ Speed<25
13	Cruise/Acceleration	3 ≤ VSP< 6; 1 ≤ Speed<25
14	Cruise/Acceleration	6 ≤ VSP< 9; 1 ≤ Speed<25
15	Cruise/Acceleration	9 ≤ VSP<12; 1 ≤ Speed<25
16	Cruise/Acceleration	12 ≤ VSP; 1 ≤ Speed<25
21	Moderate Speed Coasting	VSP< 0; 25 ≤ Speed<50
22	Cruise/Acceleration	0 ≤ VSP< 3; 25 ≤ Speed<50
23	Cruise/Acceleration	3 ≤ VSP< 6; 25 ≤ Speed<50
24	Cruise/Acceleration	6 ≤ VSP< 9; 25 ≤ Speed<50
25	Cruise/Acceleration	9 ≤ VSP<12; 25 ≤ Speed<50
26	Cruise/Acceleration	12 ≤ VSP; 25 ≤ Speed<50
27	Cruise/Acceleration	12 ≤ VSP<18; 25 ≤ Speed<50
28	Cruise/Acceleration	18 ≤ VSP<24; 25 ≤ Speed<50
29	Cruise/Acceleration	24 ≤ VSP<30; 25 ≤ Speed<50
30	Cruise/Acceleration	30 ≤ VSP; 25 ≤ Speed<50
33	Cruise/Acceleration	VSP< 6; 50 ≤ Speed
35	Cruise/Acceleration	6 ≤ VSP<12; 50 ≤ Speed
36	Cruise/Acceleration	12 ≤ VSP; 50 ≤ Speed
37	Cruise/Acceleration	12 ≤ VSP<18; 50 ≤ Speed
38	Cruise/Acceleration	18 ≤ VSP<24; 50 ≤ Speed
39	Cruise/Acceleration	24 ≤ VSP<30; 50 ≤ Speed
40	Cruise/Acceleration	30 ≤ VSP; 50 ≤ Speed

3. Results and Discussion

3.1. Data pre-processing results

The pre-processing outcomes for the operational dataset of MC in Hanoi are shown in Table 2 below.

Table 2 Random error ratios

Error types	Percentage (%)
Duplicate records	2.3
Outlying speed values	1.0
Signal gaps	2.6
Outlying power values related to misleading speeds	1.5
Total	7.4

The result in Table 3 shows that about 7.4% of the initial dataset underwent processing throughout the five steps of the filtration process. Among random errors, the signal gaps-related error is highest (2.6%), followed closely by the duplicate record-related errors (2.3%). In general, the total random errors that were detected and repaired in this study are similar to those detected in the study of Nguyen et al. [3].

3.2. Difference in VSP statistical values

In this study, VSP statistical indicators were computed for both datasets in order to quantitatively assess the difference between the WMTC standard driving cycle and the real-world driving data of MC in Hanoi. Table 3 illustrates the difference between the two datasets by some VSP statistical indicators.

Table 3 The difference between the real-world driving data and WMTC by VSP statistical values

VSP statistical indicators	Actual driving data	WMTC	Percentage difference (%)
Maximum VSP	7.33	39.02	136.74
Minimum VSP	-6.21	-26.95	125.09
Average positive VSP	1.86	6.6	112.06
Average negative VSP	-1.15	-5.97	135.39
95^{th} percentile of VSP	4.27	15.71	114.51

Table 3 illustrates that the WMTC displays significantly greater maximum and minimum VSP values than the actual driving data, suggesting more severe acceleration and deceleration situations. In addition, the real-world driving data's average positive VSP is 3.5 times lower than that of WMTC, indicating more frequent or severe acceleration episodes in WMTC. It is also evident that the WMTC does not adequately represent the real-world situations, as evidenced by the substantially larger average negative VSP and 95^{th} percentile values. In short, the percentage difference of VSP-related statistical indicators between the actual driving data of MC in Hanoi and WMTC is significant, ranging from 112.06% to 136.74%, about 124.76% on average.

3.3. Difference in VSP distribution

The VSP distributions between the WMTC and the real driving data are revealed by the boxplot comparison as presented in Fig. 2.

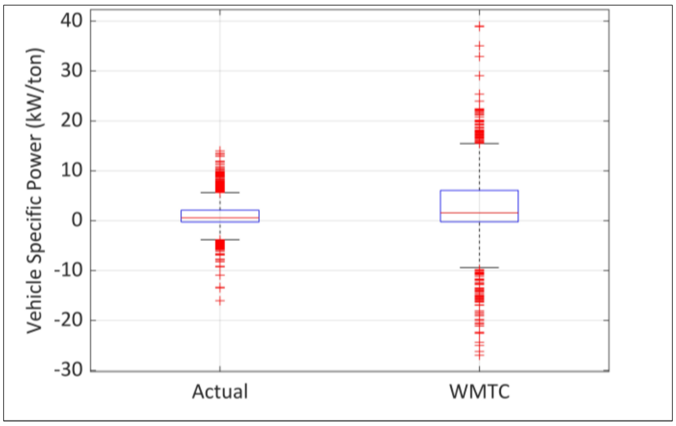

Figure 2 Comparison of the distribution between the actual driving data and WMTC

As can be seen in Fig.2, significant variations in the driving behavior characteristics are observed. More vigorous acceleration and deceleration episodes are indicated by the WMTC's larger interquartile range and noticeably greater number of extreme values, both positive and negative. The actual driving data, on the other hand, is more concentrated around the median, indicating less changeable and more moderate driving circumstances. Furthermore, a larger average power demand is identified in WMTC because WMTC's median VSP is higher than the actual data.

This study also compared the difference in operation modes distribution between the real-world driving data and WMTC as presented in Fig.3.

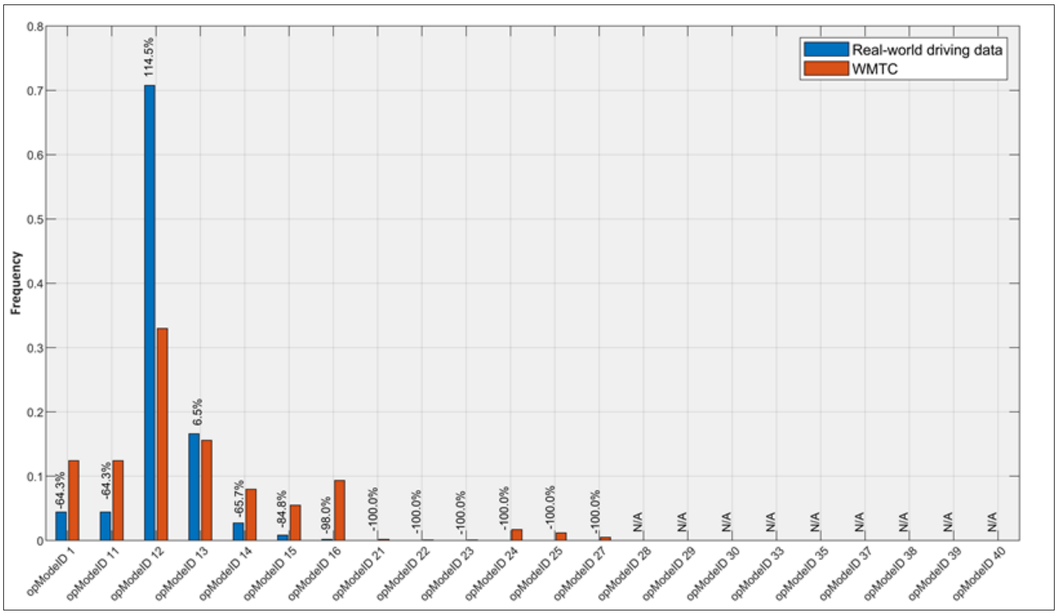

Figure 3 Comparison of the operation mode distribution between the actual driving data and WMTC

As can be seen in Fig.3, there is a significant difference in the operation mode distribution between the actual driving data and WMTC. The real-world driving data of MCs in Hanoi is predominantly concentrated within only seven operation modes, from opModeID 1 to opModeID16, with no distribution observed in the remaining modes. In contrast, WMTC has a wider operation mode distribution range, from opModeID1 to opModeID27. Both datasets have the highest concentration at opModeID12, about 70.8% for the real-world driving data and 33% for WMTC. The difference at this mode is the largest, reaching 114.5%. As defined in Table 2, the opModeID 12 corresponds with a low positive VSP ($0 \leq VSP < 3$ kW/ton). In this VSP range, MC has been demonstrated to have the potential for higher fuel consumption and emissions [5]. These imply that the MC's emissions increase when the MC runs under the real-world driving conditions.

4. Conclusion

This study demonstrates how the standardized WMTC and actual motorcycle operating in Hanoi differ significantly in terms of VSP characteristics. With an average percentage difference of almost 125%, the statistical analysis revealed that the WMTC consistently displays higher values for the 95th percentile, average positive and negative VSP, and maximum and minimum VSP. The real-world data was notably limited to a small number of operation modes, primarily in the low VSP range, which has been associated with higher emissions and fuel consumption. The highest difference reaches up to 114.5% at the opModeID12, the mode with low positive VSP. These disparities imply that local emission inventories may have a low accuracy if the MC's emissions characteristics are measured following WMTC. Thus, creating and implementing realistic local driving cycles is essential to guaranteeing the precision of vehicle emission evaluations and assisting in the formulation of sensible environmental legislation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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