Development of a Real-World Driving Cycle

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Global greenhouse gas (GHG) emissions reached a new high in 2019. Although 2020 GHG emissions were lower than those in 2019 due to the COVID-19 crisis and associated actions, GHG concentrations in the atmosphere are continuing to rise. An improvement in on-road driving behavior that would reduce fuel consumption would benefit a huge number of motorcycle riders, resulting in significant reductions in fuel consumption and CO_2 emissions. Therefore, it is essential to aggregate sufficient realistic data to generate representative real-world driving cycles that can be employed reliably for fuel consumption and exhaust emission assessment in the future.

eco-driving cycle motorcycle CO2 emissions real-world data

1. Introduction

Global greenhouse gas (GHG) emissions reached a new high in 2019. Although 2020 GHG emissions were lower than those in 2019 due to the COVID-19 crisis and associated actions, GHG concentrations in the atmosphere are continuing to rise. CO_2 emissions account for 65% of the total greenhouse gas emissions, resulting in increased GHG emissions. To reduce global warming, net-zero CO_2 emission reductions must be sustained. The transport sector has contributed to roughly 14% of global GHG emissions during the last decade [1]. The road transport sector is principally responsible because its growth is increasing, particularly in Asia due to rapid economic growth. More than half of global CO_2 emissions are emitted in Asia [2]. Therefore, the development of transportation must be based on environmental sustainability.

Hayashi et al. (2012) [3] suggested the CUTE matrix for establishing a low carbon society. The CUTE matrix introduced three strategies, including AVOID, SHIFT, and IMPROVE, to minimize fuel consumption and emissions in the transportation sector. Four measurements, including technology, regulatory, information, and economics, were also introduced. Fukuda et al. (2014) [4] proposed three strategies for establishing a low-carbon society in Asia according to the CUTE matrix. They were AVOID (e.g., transit-oriented development, TOD), SHIFT (e.g., shift to public transit) and IMPROVE (e.g., improving driving behavior using eco-driving cycles).

Among ASEAN countries, Indonesia, Vietnam, and Thailand have the highest accumulated number of motorcycles, as displayed in **Figure 1** [5]. The number of newly registered motorcycles in Thailand has risen to 21.4 million [6], leading to an increase in fuel consumption and CO_2 emissions.

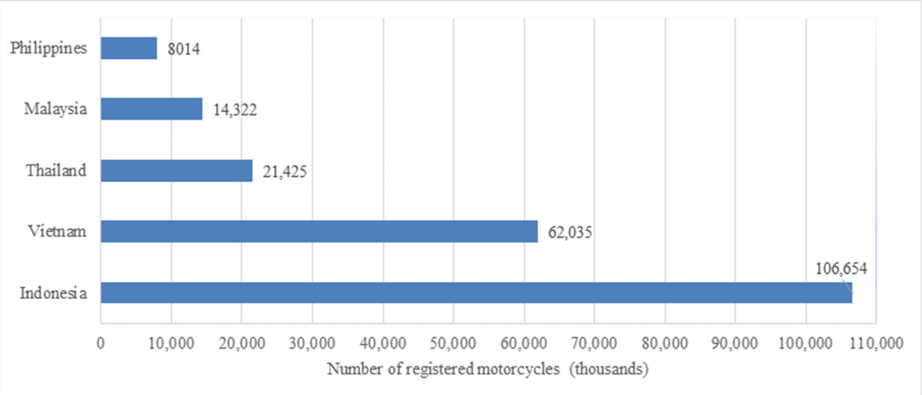

Figure 1. The number of motorcycles registered in ASEAN countries.

An improvement in on-road driving behavior that would reduce fuel consumption would benefit a huge number of motorcycle riders, resulting in significant reductions in fuel consumption and CO_2 emissions. The term “eco-driving” refers to actions that the driver can perform while driving to improve fuel efficiency or reduce CO_2 emissions. These actions include reducing deceleration, avoiding frequent use of the brakes, maintaining a suitable distance, using proper acceleration, maintaining a constant speed, and reducing the idling time [7]. Many studies have revealed that eco-driving training in passenger car drivers could improve fuel efficiency and reduce CO_2 emissions [8][9], but eco-driving training for motorcycle riders does not yet exist. Previously, eco-driving cycles for motorcycles have been developed by an optimal controller in laboratory tests [10][11]. However, these engine-controlled eco-driving cycles may not ensure that motorcycle riders can be effectively trained for eco-driving behavior because they were not developed using representative data from the real-world driving behavior of motorcycle riders. In addition, fuel consumption and air pollutant emissions of real-world driving were reported differently from those of laboratory-tested driving cycles because drivers' behavior and traffic and road conditions were not considered. Therefore, it is essential to aggregate sufficient realistic data to generate representative real-world driving cycles that can be employed reliably for fuel consumption and exhaust emission assessment in the future [12]. Nevertheless, the previous study did not reveal the development of a real-world eco-driving cycle for motorcycles, which is necessary for reducing fuel consumption and CO_2 emissions.

2. Development of a Driving Cycle

There have been many previous studies on real-world driving patterns, as indicated in **Table 1**. Many driving cycles have been developed according to vehicle type, road hierarchy, and the urban environment. In general, the development of a driving cycle can be divided into three steps: (1) route selection, (2) real-world data collection, and (3) driving cycle construction.

Table 1. Previous studies on real-world driving patterns.

Previous Studies	Data Collection	Analysis Method	Measurement and Calculation of Fuel Consumption and CO_2 Emissions	Results
Tzeng and Chen (1998) [13]	Chasing vehicle technique	Statistical method for determining the driving cycle	Chassis dynamometer test	The driving cycles for motorcycles in Taipei, Taiwan
Chen et al. (2003) [14]	Onboard measurement	Repetitive algorithm for selecting micro-trips at random	Chassis dynamometer test	The driving cycles for motorcycles for cities in Taiwan
Tsai et al. (2005) [15]	Onboard measurement	Repetitive algorithm for selecting micro-trips at random	Chassis dynamometer test	The driving cycles for motorcycles in Kaohsiung, Taiwan
Tong et al. (2011) [16]	Onboard measurement	Repetitive algorithm for selecting micro-trips at random	Not considered	The driving cycles for motorcycles and light-duty vehicles in Vietnam
Seedam et al. (2015) [17]	Onboard measurement	Repetitive algorithm using principle of least total variance in target parameters from micro-trips	Not considered	The driving cycles for motorcycles in Khon Kaen city, Thailand
Tutuianu et al. (2015) [18]	Onboard measurement	Repetitive algorithm using principle of least total variance in target parameters from short trips	Not considered	The driving cycles for light-duty vehicles
Satiennam et al. (2017) [19]	Onboard measurement	Linear regression analysis	Onboard fuel consumption sensor and gas analyzer	Real-world exhaust emission and fuel consumption models for motorcycles
Mayakuntla and Verma (2018) [20]	GPS	Repetitive algorithm using target parameters from trip segment	Not considered	The driving cycles for passenger cars in Indian cities
Wang et al. (2018) [9]	Onboard measurement	Descriptive statistics	Calculation of fuel consumption and emissions	Eco-driving training efficiency according to road type
Koossalapeerom et al. (2019) [21]	Onboard measurement	Repetitive algorithm using principle of least total variance in target parameters from micro-trips	Onboard fuel consumption sensors and gas analyzer Calculation of CO_2 equivalent emissions of electric motorcycle	The driving cycles for electric and gasoline motorcycles

Previous Studies	Data Collection	Analysis Method	Measurement and Calculation of Fuel Consumption and CO_2 Emissions	Results
Mahesh et al. (2019) [22]	GPS	Emission rate equations	Onboard gas analyzer	Real-world emission factors and emission models for motorcycles in India
Zhang et al. (2019) [23]	GPS	Micro-trip method and Markov Monte Carlo method	Onboard energy consumption sensor	The driving cycles for electric vehicles considering road environment
Lois et al. (2019) [24]	Onboard measurement	Multivariate analysis	Onboard energy consumption sensor	Eco-driving affected by driving behavior and fuel consumption influenced by congestion and road slope
Ma et al. (2019) [12]	GPS	Markov chain method	Calculation of fuel consumption	The driving cycles for large-sized vehicles
Desineedi et al. (2020) [25]	GPS	K-means clusters and Markov modeling method	Not considered	The driving cycles for buses in Chennai, India
Zhao et al. (2020) [26]	Chasing vehicle technique and onboard measurement	Markov Monte Carlo simulation method	Onboard energy consumption sensor and emissions not considered	The driving cycles for electric vehicles in Xi'an, China
Coloma et al. (2020) [8]	GPS	Multivariate data analysis	Calculation of fuel consumption and emissions	Eco-driving efficiency depending on city and road section
Liu et al. (2021) [27]	GPS	Combination of clustering and Markov chain algorithm	Onboard energy consumption sensor and emissions not considered	The driving cycles for plug-in hybrid electric vehicles
Ghaffarpasand et al. (2021) [28]	GPS	Repetitive algorithm using principle of least total variance in target parameters	Onboard measuring gas analyzer	The driving cycles for motorcycles in Isfahan

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Previously, the micro-trip method was commonly utilized to construct driving cycles, for example, [12][23][29][30]. This method divided the raw on-road driving data into many micro-trips by successive stops. The algorithm randomly and repeatedly selected a micro-trip and connected it to a previous micro-trip (if one existed) to construct a combination of micro-trips until the length of the combination of micro-trips was close to the predefined duration of the driving cycle. Recently, Mayakuntla and Verma [20] proposed an alternative trip segment method for constructing a driving cycle. This method divided raw on-road driving data into trip segments, which were more homogenous than micro-trips. This method provided a more specific indication of the driving cycle in mixed and congested traffic. However, the construction of the driving cycle requires a more complex algorithm.

Many previous studies, such as [13][14][15], used the chassis dynamometer test to measure the fuel consumption and emissions of driving cycles. In other studies, such as [8][21], equations have been used to calculate the fuel consumption and emissions. Many studies have recently developed and installed onboard sensors to measure the real-world fuel consumption and emissions, such as [19][21][22][23][26][27][28].

The eco-driving cycle was defined as a driving characteristic that consumes less gasoline fuel and emits fewer emissions. To the best of the authors' knowledge, there is a lack of research on the development of a real-world eco-driving cycle for motorcycles. A few studies [11][31][32], have attempted to develop eco-driving cycles for two-wheel and four-wheel vehicles using mathematical models and algorithms. Coloma et al. [8] developed a real-world eco-driving cycle for passenger cars by comparing the behavior of drivers before and after an eco-driving training course. Nevertheless, no study has been done on a real-world eco-driving cycle for motorcycles.

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