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Research article

Preliminary study on-road test for performance evaluation of electric motorcycles in Vietnam

Le Duc Thinh, Ngo Thanh Tan, Dang Trung Duan, Ngo Khanh Hieu*

ABSTRACT
In Vietnam, electric motorcycles (EMs) have recently emerged as reliable, eco-friendly alternatives to conventional gasoline-powered vehicles. However, because electric motorcycles are relatively new in the motorcycle industry in Vietnam, consumers often lack access to essential data for assessing the performance and construction quality of EMs, which in turn affects their purchasing decisions. To address this challenge, our research presents an experimental methodology and road-testing procedure for EMs, incorporating a range of assessment criteria. Our investigation focused on two VinFast integrated battery packs of Lithium-Ion (NMC) type with a capacity of 22 Ah, and two VinFast IMPES electric motorcycles. The study enlisted the participation of five male volunteers and involved traversing two distinct routes: a city route with an average distance of 10 km and a highway route with an average distance of 24 km. In total, the study encompassed over 4000 km of travel and 70 charge cycles. The results have shown that the energy consumption ranged between 18.1 and 20.1 with an average energy consumption of 20.47 , which is approximately 0.13 USD for 50 km. With an initial battery capacity of 28%, the average charging time is 3 hours 24 minutes, with a charging efficiency of 94%. The variance between the theoretical model and test results fell within the range of 24.46%. This methodology can be applied to various models of electric motorcycles, providing both manufacturers and users with a means to gather operational parameters and assess the critical performance aspects of these vehicles It is important to note that the outcomes are still influenced by the actions of the rider.
Key words: Electric motorcycles, process, energy consumption, efficiency, battery

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INTRODUCTION

Motorcycles serve as a primary mode of transportation in many urban areas of Vietnam. As of 2018, the registered motorcycle count stood at approximately 58 million, experiencing a steady annual growth rate of 7.33%[1]. In Ho Chi Minh City, the nation's commercial center, private motorcycles make up 74% of the overall number of vehicles[2]. However, the prevalence of gas-powered motorcycles also contributes to air pollution, with both Hanoi and HCMC ranking among the top 15 most polluted cities in Southeast Asia[3].

As a result, electric motorcycles have gained popularity as a cleaner alternative to their gasoline-powered counterparts. These electric motorcycles are powered by electric motors that rely on rechargeable batteries, which are usually lithium – ion batteries. Lithium-ion batteries offer several advantageous characteristics, including high efficiency, extended cycle life, impressive energy density, and notable power density[4]. The International Association of Public Transport (UITP) estimated that by 2019, Vietnam would see a total of 5 million electric two-wheelers on its roads[5]. In 2019, the Registration Department reported the presence of 11 companies engaged in the production of electric two-wheelers, with a combined output of 52,938 vehicles. Notable players in the market include VinFast, Pega (Vietnam), Yadea (China), and Mbigo (South Korea), which collectively dominate market share.

Despite the growing popularity of electric motorcycles in Vietnam, research examining their performance characteristics remains scarce and barely noticeable in Vietnam. Diverging from prior theoretical investigations, this study adopts an experimental approach, making it universally applicable to all-electric motorcycles across various operational scenarios. Moreover, it facilitates the accumulation of operational data for future research and development. This research also merges modeling of an electric motorcycle with road testing to ascertain energy efficiency during operation. Beyond energy efficiency, the study assesses additional performance parameters such as maximum speeds, achievable distances, operational costs, and charging/discharging times.

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PROBLEM STATEMENT AND MODEL OF ELECTRIC MOTORCYCLE ENERGY

The energy consumption of the EM was modeled using the block diagram shown in Figure 1 [6]. This was determined by the amount of energy required for both propelling the electric scooter and powering any accessories or loads. Meanwhile, the needed energy was calculated by its dynamic properties. As a result, the longitudinal modeling of the scooter was necessary.
The traction battery served as the electric power source. Energy conservation laws state that total energy input equals total energy output plus energy loss [6], so:

$$E_{Batt} = E_{Tractrion} + E_{Load} + E_{Loss} - E_{regen} \quad (1)$$

where, $E_{Traction}$ is the overall amount of energy needed to move the vehicle; E_{Load} is the quantity of energy required to power all the vehicle's accessories; E_{Loss} is the total energy loss due to inefficiency in the vehicle energy conversion and E_{Regen} is the total energy produced when a vehicle uses regenerative braking, respectively.
According to [7], it is defined that $E_{Traction}$ + E_{Load} + E_{Regen} is equivalent to the total energy drawn from the battery and it is denoted as E_{Batt_out}. Therefore, (1) can be rewritten as:

$$E_{Batt} = E_{Bat\_out} - E_{Regen} \quad (2)$$

it can be expressed as:

$$E_{Batt} = \int_{Traction} P_{Batt\_out}(t)\,dt - \int_{Regen} P_{Batt\_in}(t)\,dt \quad (3)$$

$$P_{Batt\_out} = \frac{R_{Total}.V_{EM}}{\eta_{PowerTrain}} \quad (4)$$

$$P_{Batt\_in} = \beta.P_{Regen} \quad (5)$$

where P_{Batt_out} is the total power (including loss) to propel the EM. The traction battery should be able to supply the power required to drive the motor (overcome all the resistive force (R_{Total}) and losses in its power transmission ($\eta_{PowerTrain}$) system) at a specified velocity (V_{EM}). P_{Batt_in} is the total amount of energy the traction battery recovers while braking.
The dynamic equation of motion for the motorcycle can be used to calculate its overall resistive force while it is in motion. This was discovered by employing the longitudinal model depicted in Figure 2. [8]
In Figure 2, the total resistive forces for a moving electric scooter in an inclination road angle of α (using the longitudinal model) can be derived as follows.

$$R_{Total} = R_{Traction} \quad (6)$$

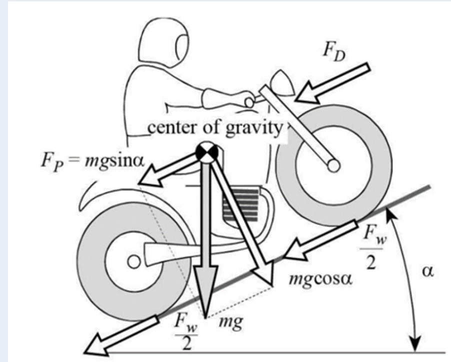

Figure 2: Electric motorcycle dynamics longitudinal with rider diagram

$$P_{Wheel} = F_{Traction}.V_{EM} \quad (7)$$

$$F_{Traction} = F_{Drag} + F_{Rollinesistance} + F_{Grade} + F_{Inertia} \quad (8)$$

$F_{Traction}$ the overall force at work, is the product of the forces listed below.
Drag calculation equation:

$$F_{Drag} = \frac{1}{2}\rho C_d A_f V_{EM}^2 \quad (9)$$

Rolling resistance calculation equation:

$$F_{Rollinesistance} = C_{RR}.M_{EM}.g.\cos\alpha \quad (10)$$

Slope resistance calculation equation:

$$F_{Grade} = M_{EM}.g.\sin\alpha \quad (11)$$

Inertial force calculation equation:

$$F_{Inertia} = M_{Inertia}.a \quad (12)$$

$$M_{Inertia} = \varepsilon_i.M_{EM} \quad (13)$$

Table 5 displays the symbols used in the aforementioned equation. Given that the road is assumed to be straight in this report, α is zero.
Based on (1) to (13), it is easy to investigate and compare energy consumption via theoretical and experimental.
The operating energy efficiency is described by (14). This energy (E_{Wheel}) is defined as the output energy by equation (7). Energy consumption (E_{Batt_real}) is determined by measuring instruments from the road test process.

$$\eta_{Energy} = \frac{E_{Wheel}}{E_{Batt\_real}}.100\% \quad (14)$$

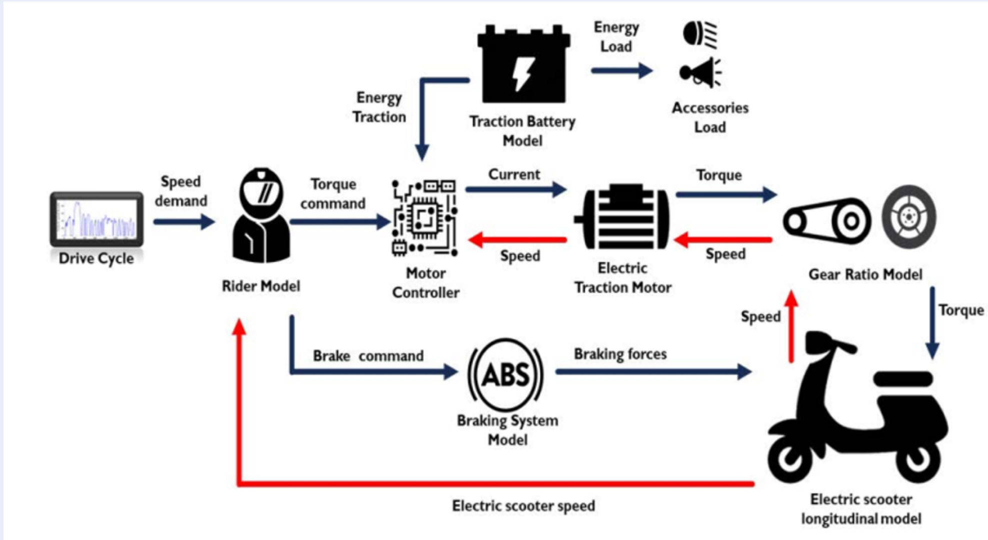

Figure 1: Electric motorcycle energy flows model architecture

TEST APPROACH AND FEASIBILITY FOR PERFORMANCE OF AN ELECTRIC MOTORCYCLE ENERGY

To obtain precise and reliable data, it is crucial to establish rigorous test procedures and measurements for electric motorcycles. As a result, our team has created a thorough test methodology that is outlined in this section.

Monitoring equipment requirements.

The following measuring equipment and capabilities are necessary based on the measurement standards (Table 1):

GPS equipment tracking: GPS tracker enables the collection of speed, location, and altitude data via a built-in barometric altimeter, allowing for the calculation of road grades based on distance and height. The GPS tracker is meticulously covered to prevent pressure changes brought on by movement that could impact the altitude measurements. An extra antenna can also be utilized to prevent GPS signal losses.

Battery Parameter Measuring: Current is monitored on the circuit that connects the battery to the electric motor, while voltage probes are inserted directly into the battery terminals of electric motorcycles. The primary driver, logging on a 01 Hz basis, acquired the signals that the probes provided. Data loss can be prevented throughout the road test process by using a solid-state disk.

Road test implementation

The experimental process was modeled according to the flowchart depicted in Figure 3.

Route Planner

The selection of route is adaptable and may include either a highway, an urban road or both, depending on the operational context. Driving parameters including distance, duration, stop duration, and speed are used to fully assest each type of route in accordance with driving cycles like NEDC (New European Driving Cycle) and WLTC (Worldwide Harmonized Light Duty Test Cycle). Additionally, elements such as the traffic conditions on these roads, including whether they are favorable or unfavorable, the number of intersections, the volume of traffic, the frequency of traffic jams, etc... should also be considered.

Installation of monitoring equipment

Prepare all the measuring devices suggested in Table 1 and install them as shown in Figure 4 below. Install the battery, GPS speedometer, Power Meter, and mobile phone, and connect the application to the vehicle.

Inspection

To ensure optimal accuracy, every monitoring equipment is inspected. Inspect the GPS Tracker first (time, time zone, unit, satellite connection status). It will take between 30 and 120 seconds to establish the signal to the satellite. However, it is advisable to wait 60

Table 1: TECHNICAL DESCRIPTION OF THE EQUIPMENT

No.	Monitoring equipment	Data acquired	Accuracy
1	GPS Equipment Tracking	Speed (km/h); Time (s) Altitude (m); Location	Altitude 3 m Speed 0.1 km/h
2	Electric-Energy Meter	Consumption Charge Energy	1%
3	Battery Parameter Measuring	Voltage (V); Current (A)	Voltage 1% Current 2%
4	Human Machine Interface Display in EM	SoC (%); Speed (km/h)	SoC 1% Speed 1 km/h
	Connected Vehicle Applications (extra)	Battery's temperature (oC); Charge cycles; Configure	1oC

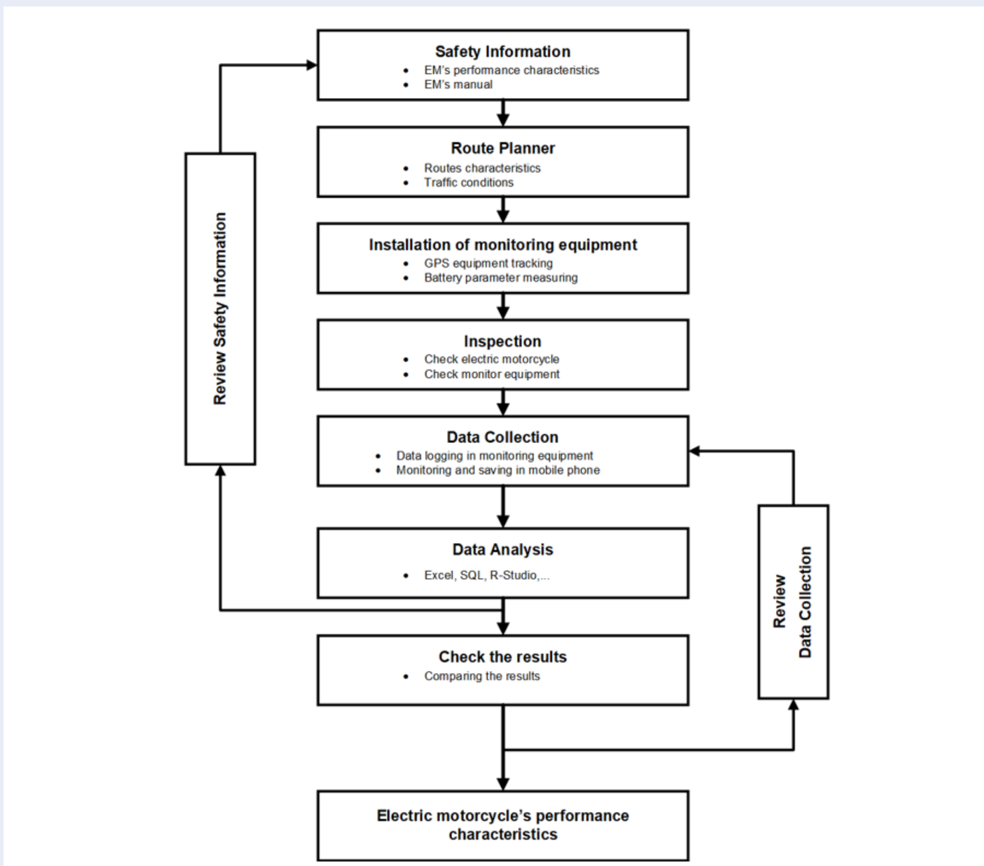

Figure 3: The experimental procedure framework

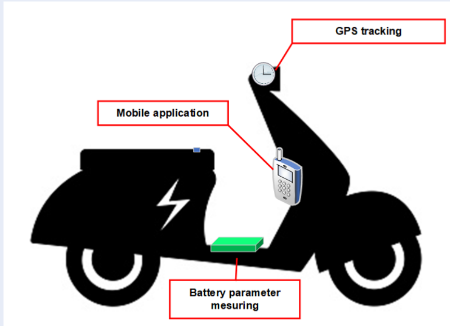

Figure 4: Installation of monitoring equipment in EM

seconds after the GPS Tracker obtains the satellite signal before moving.

Second, check the application's vehicle connection status. Modern EMs have a built-in application by the manufacturer that enables connection to the motorcycle via smartphones running Android or iOS operating systems. Users can manage the vehicle by keeping track of the battery, they can also find a location and plan their route. To complete the connection check, you must first read the user manual for the vehicle management software that each manufacturer offers. A battery parameter measurement should also be checked. Prior to unlocking the electrical system for the road test, check the vehicle's condition (tires, brake system, electric throttle, etc.)..

Check the vehicle's brake by applying the front and rear brake one at a time, then push the vehicle forward and backward and make sure it doesn't move. Turn the lock to the OFF position, squeeze and release the throttle to verify if it works properly. Confirm both tires are at operational pressure, anomalies should not exist on tires. In this situation, since the monitoring equipment is unreliable, a different device will be used and it should be verified again.

Figure 5: Tested Electric motorcycles of IMPES

Data Analysis

The data logging program on monitoring equipment should be terminated. The data collected by the logging programs will be saved in a solid-state disk or the mobile device's internal storage. Continue data analysis by encoding, filtering, and sorting data using software like excel, SQL, and R-studio.

Check the results

Throughout the data collection process, occasional singular values may appear, potentially distorting the integrity of the analysis outcomes. Therefore, to ensure the accuracy of the results, it is necessary to compare each result with one another and with the theoretical results calculated from section 2. A comparison with the published results should also be made.

CASE STUDY ON ROAD TEST FOR PERFORMANCE OF AN ELECTRIC MOTORCYCLE IN HO CHI MINH CITY

The process was applied in Vietnam's Ho Chi Minh City. Two IMPES electric motorbike models with integrated battery packs from VinFast were the subjects of the test. In Figure 5, this is displayed. Table 2 provides information on the prototype specifications.

Table 2: IMPES PROTOTYPE SPECIFICATIONS

Specifications	
Type	Electric scooter
Range per charge	70 km/charge
Top speed	49 km/h
Electric motor /power / Torque/max rpm	BLDC / 1.2 kW 80 N.m / 550 rpm
Battery/Capacity	Li-Ion (NMC) / 22 Ah
Charger type	400 W
L x W x H (mm)	1800 Í 710 Í1070
Weight	75 kg

The monitoring device has a GPS module to capture the dynamic travel profile (including location and vehicle speed). To measure the electrical energy used by the battery and charger, electric energy meters are used. The description of the equipment used is shown in Table 3.

To conduct the road test, five male volunteers were chosen. The volunteers are all students from HCMUT with an average age below 22 and average weight ranging from 65 to 75 kg. Figure 6 and Figure 7 show a 10-kilometer route that was used in HCMC. Two traffic scenarios, one under clear conditions at 6 AM and one under gridlock circumstances at 5 PM, were included. Each volunteer participated an average of 8 different laps.

Table 3: TECHNICAL DESCRIPTION OF THE EQUIPMENT

Monitoring equipment	Accuracy
GPS (iGS130) (IGSPORT)	Altitude 3 m 95% of time
Power Meter and Data Logging application (Self-Study)	Current 0.0591 A (Comparing to Fluke 376) Voltage 0.0567 V
Pansong PS 178 (LSE)	Power meter ±1% of the measured value

Figure 8 presented a second route of 23 km. It consists of 5 km of urban road and 18 km of motorway. The first leg starts at 6 am, and the return leg starts at 9 am. Each volunteer underwent six experiments sessions in total.

It is possible to compare the motorcycle's performance characteristics between experiment and theory using (1) Table 4's input parameters and data from the experimental method (13) (see Table 5). Via (14), it also assesses energy efficiency. Assuming the route is flat (α=0) and the wind speed is not taken into account. However, it should be noticed that when the on-road monitoring was performed there were no windy days.[9]

On the other hand, the charger is also evaluated in Figure 9. The energy input and output of the charges are recorded by PS 178 and Power Meter. Based on this data, the charging efficiency and the operating cost are defined easily.

Table 4: IMPES'S CHARGER SPECIFICATIONS

Specifications	
Input	220VAC/ 50-60Hz/ 2.5A
Output	57.75VDC/ 7.0 A

RESULTS AND DISCUSSION

This article intends to introduce the road test procedure for electric motorcycles with evaluation criteria including top speed, top distance, energy efficiency, operating costs, top charging time and top discharging time.

Figure 9: The layout of the charging process

Table 6: CHARGING RESULTS

Charging time	Voltage max	Current max	Power max
3 h 24	**57.5 V**	**6.8 A**	**383.5 W**
Rising temperature	AC Energy consumption	DC Energy consumption	Charge efficiency
5^{o}C	900 Wh	862 Wh	94%

Charger's performance

Charging results are obtained from charging at a room temperature of 26^{o}C. The SoC begins at an average of 28%, and the average temperature of the battery is 30^{o}C. Charging ends when the capacity reaches 100%, and the charger light turns green. The results obtained in Table 6 are the average values from 70 battery charging cycles.

The results on the charger's performance are consistent with what the manufacturer publicized. The charger works using constant-current-voltage (CC-CV) charging techniques. Figure 10 and Figure 11 display the correlation of electrical parameters (voltage, current) over time. It reflects the actual features of lithium-ion batteries as described in theory.

General performance

The average speed and the average DoD consumption per route are shown in Table 7. Furthermore, to avoid voiding the warranty of the vehicle, it is required to keep the battery remainder at least 20% SoC. The total distance is about 4000 km during the experiment.

The energy consumption and energy efficiency for each route under each scenario are shown in Tables VIII and IX. The difference between theoretical and experimental results has an average inaccuracy of 24.46%. It means that the mathematical models are not detailed enough to accurately describe the operating characteristics of electric motorcycles in reality due to the influence of traffic conditions, driving

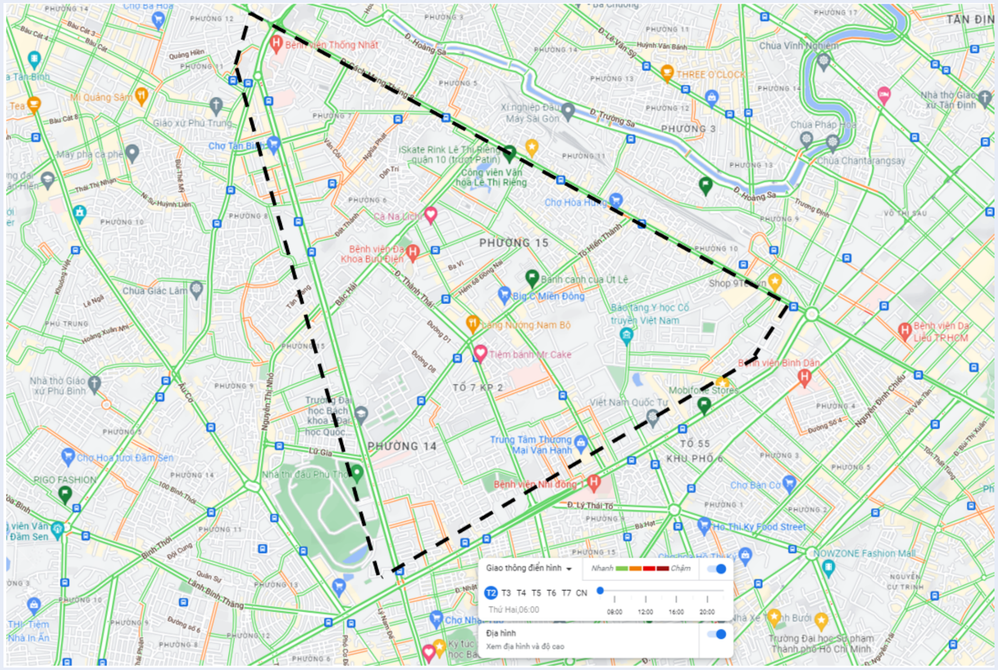

Figure 6: Case study route, 10 km in clear condition at 6 am.

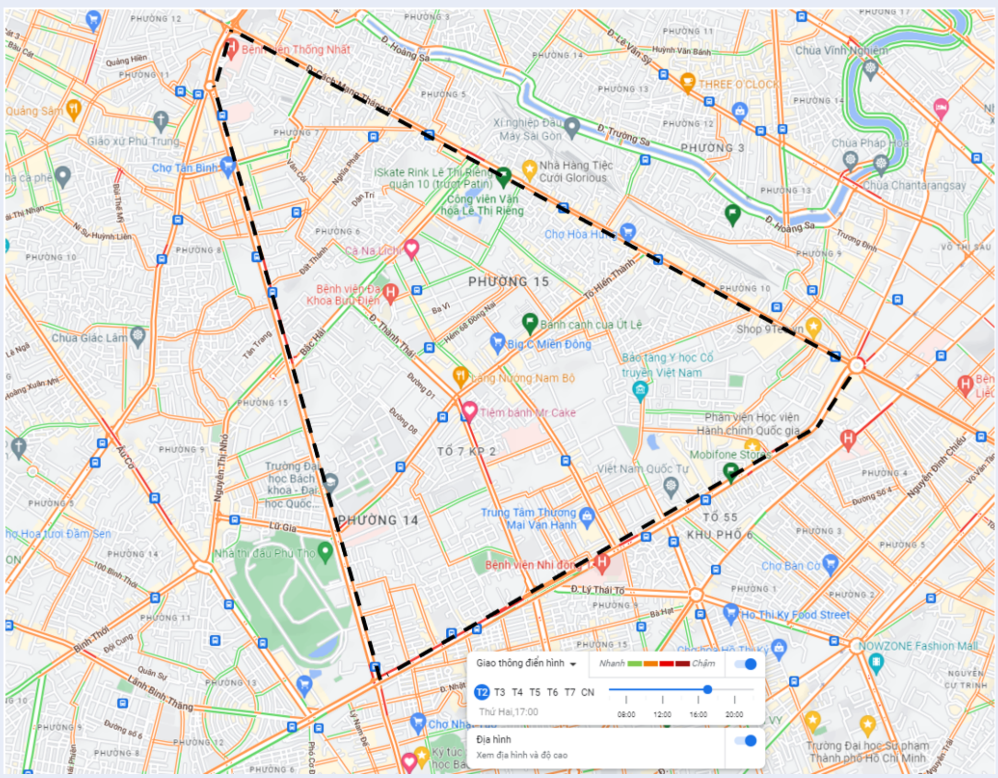

Figure 7: Case study route, 10 km in clear condition at 5 pm.

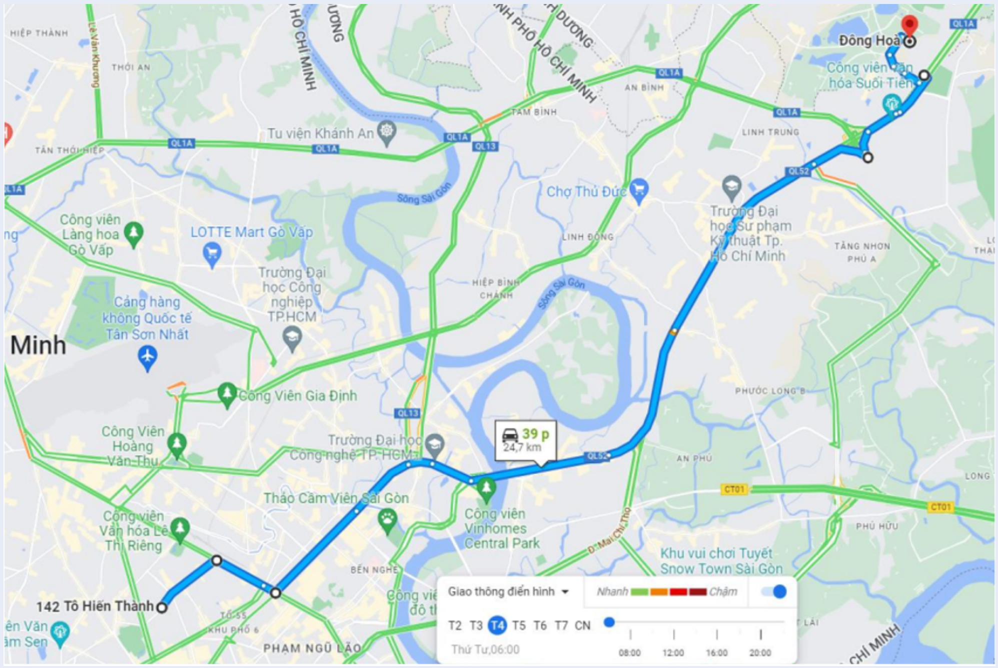

Figure 8: Case study route, long-range 23 km.

Table 5: THE ELECTRIC MOTORCYCLES PARAMETERS FOR MODELING

Parameter	Notes	Values	Units
M_{EM}	Total EM mass including its rider	140 / 150	kg
g	The gravitational constant	9.81	m/s2
ρ	Air density	1.164	kg/m3
A_f	Frontal area	0.65	m2
C_d	The aerodynamic coefficient	0.75	-
C_{RR}	The rolling coefficient	0.014	-
ε_i	The effect of the translational mass of powertrain rotating components	1.0	%
β	Energy regen coefficient	0.5	%

behavior, and different parameters in each operating condition. The inability to gather the energy required to run all the vehicle's accessories (E_{Load}) accounts for the significant discrepancy between theoretical results and experimental results. Our team needs to discover or develop a tool that can collect data from a vehicle's accessories to improve the models.

Energy consumption rate

Figure 12 and Figure 13 shows the distribution of energy consumption at the speed.

The energy usage is spread out between 18.1 and 20.1 Wh/km. There are 20.47 Wh/km on average. The Toyotron Dragon-G electric motorcycle (capacity 1000 W, lead acid battery 60 V - 20 Ah, and weight 95 kg), which was experimentally operated at Khon Kaen City Thai Lan, uses 28 Wh/km less energy than IMPES. In addition, the running cost of 0.13 USD/50 km is 8 times less than that of a motorcycle fueled by gas, which is 1.02 VND/50 km based on the current electricity rates [10].

Energy efficiency

The results obtained the relationship between average speed and energy efficiency from the experimental data (see Figure 14). To understand how traffic

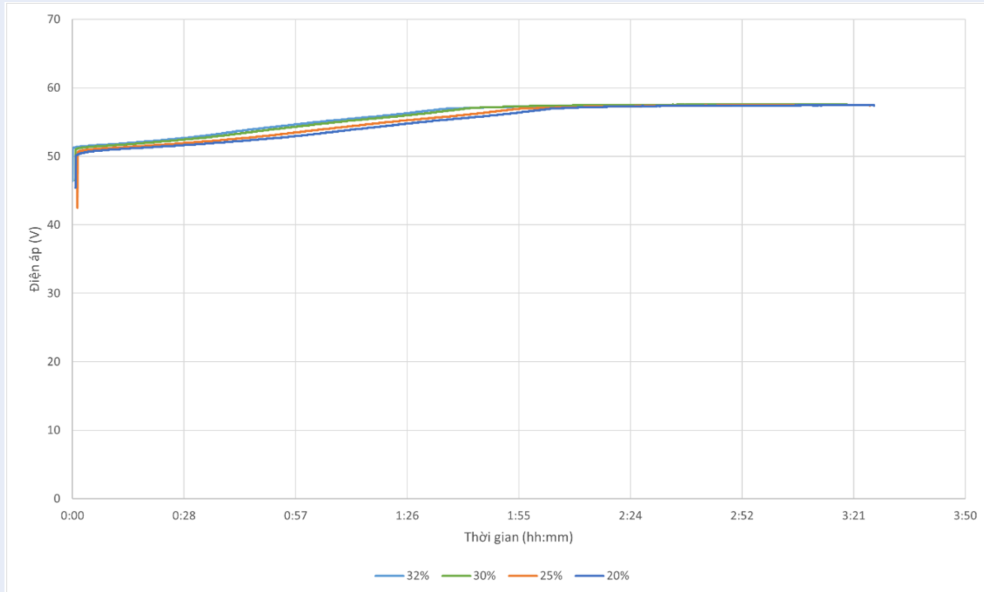

Figure 10: Charging voltage during the charging time

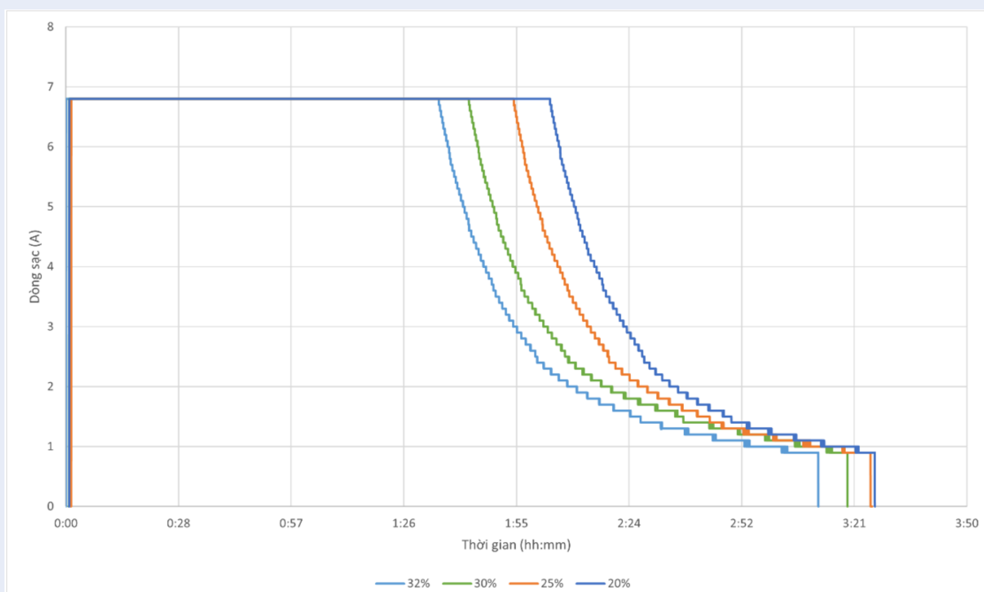

Figure 11: Charging current during the charging time

Table 8: ENERGY CONSUMPTION

Conditions	10km Clear	10km Traffic jams	23km First	23km Return
Speed (km/h)	30.6	19	35.9	32
Experimental results (Wh)	**212**	**184**	**472**	**432**
Theoretical results (Wh)	144	127	399	346
Error (%)	32.01	31.18	15.53	19.84
Mean Error		**24.46 %**		

Table 9: ENERGY EFFICIENCY

Conditions	10km Clear	10km Traffic jams	23km First	23km Return
Speed (km/h)	30.6	19	35.9	32
Experimental results (Wh)	**73**	**66**	**83**	**85**

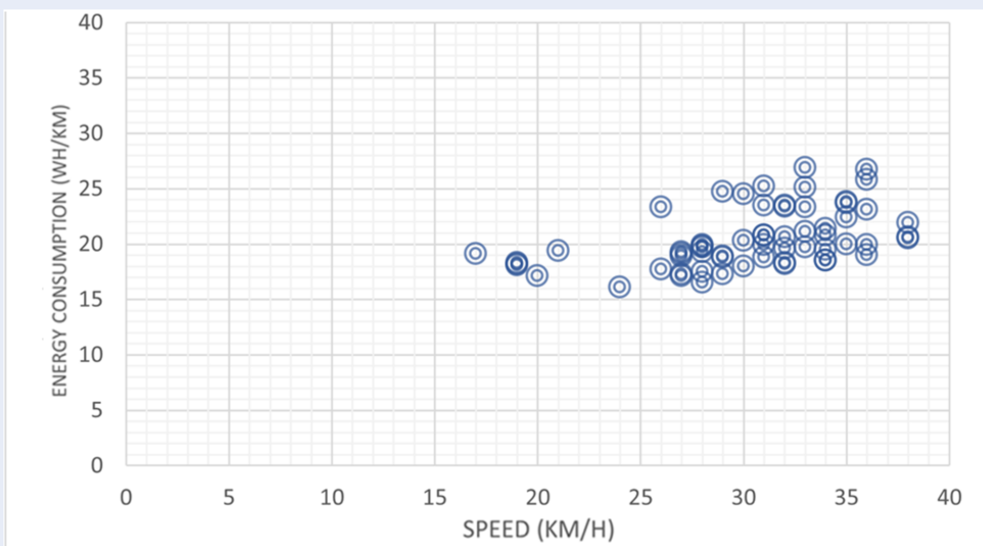

Figure 12: Energy consumption of IMPES

conditions affect transmission performance, this article covers both clear and crowded roadways.

1. A 10 km route in the city: The energy efficiency is 73.4% and 66.1% in clear and traffic conditions respectively.
2. A 23 km route in motorway: The energy efficiency is 68.1% and 88.5% in the urban road and motorway respectively.

In general, energy efficiency is distributed in the range of 66.3–84.3%. The average is 75.45%.

Electric motorcycles are now capable of replacing gas-powered motorcycle explosive motorbikes both in terms of cost and operation.

CONCLUSION

The article in the current study has suggested a preliminary road test approach used to gauge and gather data

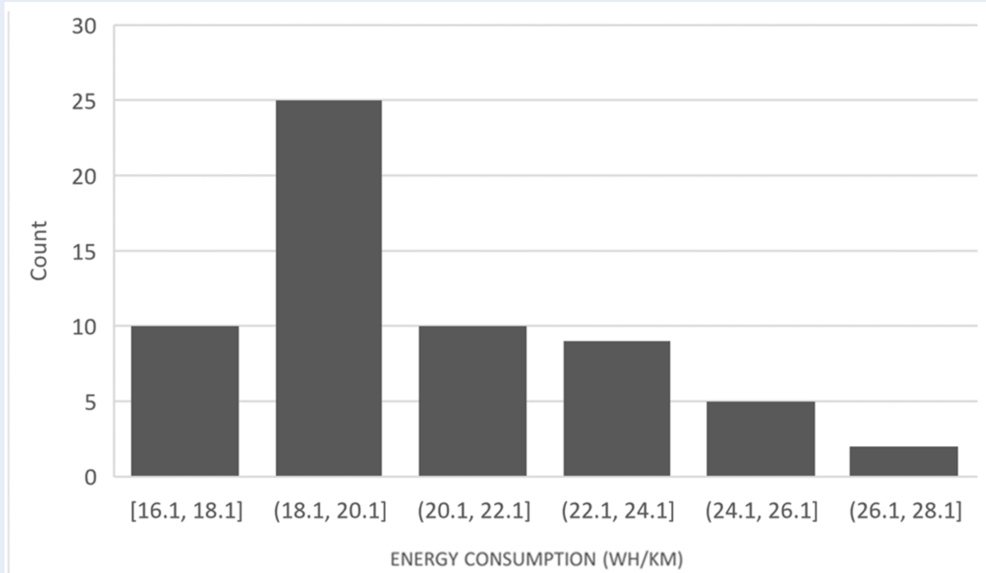

Figure 13: Distribution of energy consumption of IMPES

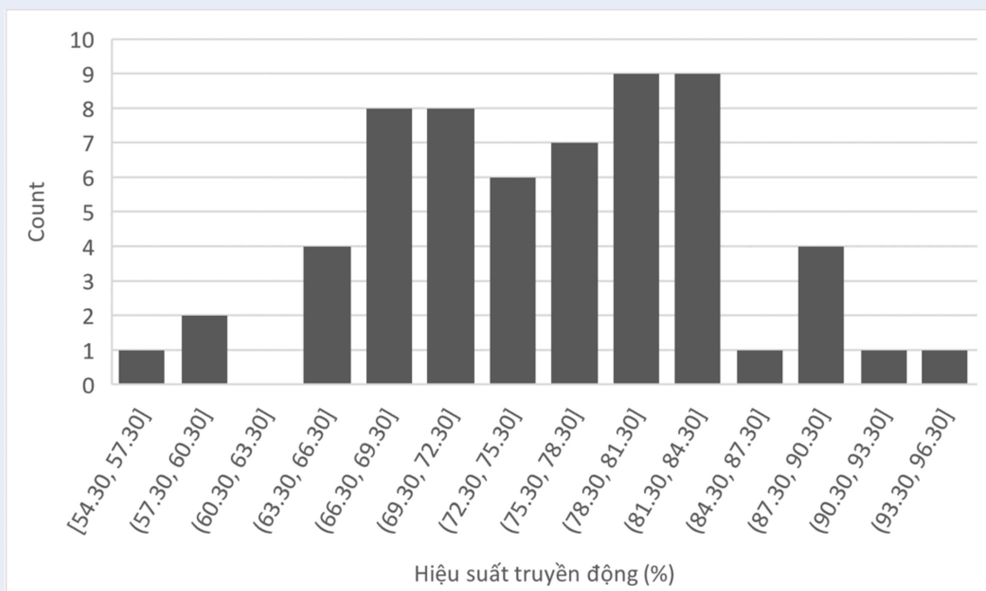

Figure 14: Distribution of energy efficiency of IMPES

Table 7: GENERAL PERFORMANCE RESULTS

Condition	10km Clear	10km Traffic jams	23km First	23km Return
Speed (km/h)	30.6	**19**	35.9	32
DoD (%)	17	**14**	39	37
Distance Max (km)	50	**60**	46	46

on the performance characteristics of electric motorcycles. To emphasize the requirements of each, a thorough description of phase working is given, along with information on the monitoring apparatus. The ability to identify the performance parameters of the electric motorcycle is a highly desirable aspect of the current method. Table 10 provides a sample application of IMPES in HCMC:

Table 10: IMPES'S PERFORMANCE CHARACTERISTICS

Criteria	Results
Charge time	3 hours 24 minutes
Charging efficiency	94%
Maximum speed	Under 50 km/h
Maximum distance	60 km
Energy consumption	20.47 Wh/km
Energy efficiency	75.45%
Operating cost	0.13 USD/50km

These outcomes fully satisfy the specifications. When the contributing factors, traffic, and driving behavior are not fully addressed during the implementation process, the benefits are still limited.

ACKNOWLEDGEMENT

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NOMENCLATURE

EM: Electric Motorcycle
HCMC: Ho Chi Minh City
HCMUT: Ho Chi Minh City of Technology
VNU-HCM: Vietnam National University, Ho Chi Minh City
UITP: International Association of Public Transport
WLTC: Worldwide Harmonized Light Duty Test Cycle
NEDC: New European Driving Cycle
GPS: Global Position System
SoC: State of Charge
DoD: Depth of Discharge
CC: Constant current
CV: Constant voltage

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

AUTHOR CONTRIBUTION STATEMENT

NGO K.H. analyzed the model of electric motorcycle energy, and participated in developing its test approach. LE D.T. analyzed the significance of the energy model for electric motorcycle, and participated in performing/analyzing the tests on road in Ho Chi Minh city. NGO T.T. participated in contributing to the equipments for testing on road. DANG T.D. participated in testing data interpretation. All authors participated in contributing to text and content of the manuscript, including revisions and edits. All authors approve of the content of the manuscript and agree to be held accountable for the work.

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Tạp chí Phát triển Khoa học và Công nghệ – Engineering and Technology 2023, 5(SI2):10-23

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Nghiên cứu sơ bộ về phương pháp thực nghiệm đánh giá đặc tính vận hành của xe máy điện tại Việt Nam

Lê Đức Thịnh, Ngô Thanh Tân, Đặng Trung Duẩn, Ngô Khánh Hiếu*

TÓM TẮT

Tại Việt Nam, xe máy điện (EM) gần đây đã nổi lên như một lựa chọn thay thế đáng tin cậy, thân thiện với môi trường cho các phương tiện chạy bằng xăng thông thường. Tuy nhiên, do xe máy điện còn khá mới trong ngành công nghiệp xe máy ở Việt Nam nên người tiêu dùng thường thiếu khả năng tiếp cận với dữ liệu cần thiết để đánh giá hiệu suất và chất lượng của xe máy điện, từ đó ảnh hưởng đến quyết định mua hàng của họ. Để giải quyết thách thức này, nghiên cứu của chúng tôi trình bày một phương pháp thử nghiệm và quy trình thử nghiệm trên đường dành cho xe máy điện, kết hợp nhiều tiêu chí đánh giá. Đối tượng nghiên cứu của bài báo tập trung vào hai bộ pin của VinFast loại Lithium-Ion (NMC) có dung lượng 22 Ah và hai xe máy điện VinFast IMPES. Kết quả nghiên cứu được triển khai có sự tham gia của 5 nam tình nguyện viên với hai tuyến đường riêng biệt: tuyến đường trong thành phố với khoảng cách trung bình 10 km và tuyến đường cao tốc với khoảng cách trung bình 24 km. Tổng cộng, nghiên cứu đã bao gồm hơn 4000 km di chuyển và 70 chu kỳ sạc. Kết quả cho thấy mức tiêu thụ năng lượng dao động trong khoảng 18.1 đến 20.1 Wh/km với mức tiêu thụ năng lượng trung bình là 20.47 Wh/km, tương đương khoảng 0.13 USD cho 50 km. Với dung lượng pin ban đầu là 28%, thời gian sạc trung bình là 3 giờ 24 phút, hiệu suất sạc là 94%. Phương sai giữa mô hình lý thuyết và kết quả kiểm định nằm trong khoảng 24.46%. Phương pháp này có thể được áp dụng cho nhiều mẫu xe máy điện khác nhau, cung cấp cho cả nhà sản xuất và người dùng phương tiện để thu thập các thông số vận hành và đánh giá các khía cạnh hiệu suất quan trọng của những phương tiện này. Giai đoạn phát triển tiếp theo là tìm hiểu và đánh giá về hiệu suất của xe máy điện dựa trên người sử dụng vì kết quả vẫn bị ảnh hưởng bởi hành vi của người lái.

Từ khoá: Xe máy điện, quy trình, năng lượng tiêu thụ, hiệu suất, pin

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