Real-World Electricity Consumption Properties of Ultra-Compact Electric Vehicles

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ABSTRACT: This study investigated the electricity consumption properties of ultra-compact electric vehicles (UCEVs) in the real world. Vehicle running data collected in a social experiment of UCEVs implemented in Kato City, Japan, were used for an empirical study. The major findings suggest: 1) the average electricity consumption rate of UCEVs is 89.8 Wh/km; 2) UCEVs can reduce the CO2 emissions from vehicle use by approximately 67.0%; 3) gasoline cost savings amount by adopting UCEVs varies from 9,000 to 86,000 Yen annually for participants owning gasoline cars; 4) UCEVs have a lower maximal and average speeds than gasoline cars.

KEY WORDS: environment-energy-resources, greenhouse gas, personal mobility, test/evaluation / Ultra-compact electric vehicle, Electricity consumption rate, CO2 emission, Cost savings, Running characteristics (D2)

1. Introduction

New means of transportation are emerging in rapid succession due to various mobility needs corresponding to environmental problems and sophistication of technologies supporting them (1). If we have a new category of mobility vehicle that is best suited for one- or two-person mobility with ultra-compact and ultra-lightweight body (i.e., ultra-compact electric vehicle or ultra-compact personal mobility vehicle), there is the possibility of radical energy savings without giving up the liberty to move and without impacting economic activity (2). To understand the questions of where and how the optimal utilization of such vehicles can be realized in daily life, several social experiments have been implemented in Japan (3). Meanwhile, from the user’s viewpoint, the proposal of deploying personal mobility vehicles is suggested for different regions in Toyota City, including the city center, residential areas, and hilly and mountainous areas (4).

Although many social experiments and proposals for penetrating the ultra-compact electric vehicle have already been implemented, evaluation of the electricity consumption rate, CO2 reduction effects, and cost savings in the real world have seldom been observed in most previous studies. This study investigates the real-world electricity consumption rate, the effects of CO2 reduction, and the gasoline cost savings of the ultra-compact electric vehicle. The vehicle running data collected from a social experiment concerning ultra-compact electric vehicles implemented in Kato City in Japan were used for this study. In the social experiment, the ultra-compact electric vehicle is supposed to be used as an official vehicle of the municipal government and as a private vehicle. Also, this study makes a comparison of the vehicle running characteristics between gasoline passenger cars and ultra-compact electric vehicles in the real world.

The rest of this study is organized as follows. Section 2 makes a brief introduction of the social experiment concerning the ultra-compact electric vehicles implemented in Kato City, Japan. The experimental results of the average electricity consumption rate, reduction rate of CO2 emission, and gasoline cost saving amount are reported in section 3. Section 4 compares the differences in running characteristics between gasoline passenger cars and ultra-compact electric vehicles. In section 5, concluding remarks are presented with a discussion regarding future studies.

2. Introduction of the Social Experiment

The social experiment concerning the ultra-compact electric vehicle was implemented in Kato City, Hyogo Prefecture, Japan. As it is depicted in Fig. 1 (5), Kato City is located just south of the center of Hyogo Prefecture. Two highway interchanges on the

Fig. 1. Location of Kato City (5).
Chugoku expressway are located inside the city. Thus, Kato City plays an important role as the manufacture and logistics basement. Like other local cities in Japan, private cars are the dominant mode of transportation for residents. As a result, it is a challenge for the local government to push ahead with eco-friendly mobility. The local government has proposed several measures to promote eco-friendly mobility (6), and this social experiment was implemented as part of these measures from October 1 to November 31, 2014.

2.1. Participants in the experiment

In the social experiment, two ultra-compact electric vehicles were supposed to replace the official and private vehicles. The two vehicles used in the social experiment were “COMS” manufactured by the Toyota Auto Body Co., Ltd., as shown in Fig. 2.

Fig. 2. Two ultra-compact electric vehicles.

Employees of two divisions of the local government, i.e., the Elderly Care Division and the Life Division, joined the experiment as participants and used the ultra-compact electric vehicle as their official vehicle. Meanwhile, 11 individual participants from members of the non-profit organization Kato eco-tai as well as faculty and students of the Hyogo University of Teacher Education participated in the experiment and used the ultra-compact electric vehicle as their private vehicle. The period of the experiment was approximately one week for the individual participants and less than that for the local government employees. Informed consent was obtained from all participants.

2.2. Data collection

To explore the electricity consumption rate, the distance traveled and electricity consumption of the ultra-compact electric vehicle were recorded during the period of the social experiment. The distance traveled was calculated based on the odometer reading inside the vehicle. The electricity consumption amount was acquired using a power meter TAP-TST11 manufactured by the Sanwa Supply Co., Ltd. This meter recorded the accumulative electricity consumption when the electric vehicle was charged. Meanwhile, we used a GPS logger to record the vehicle’s running characteristics. The measuring devices (GPS logger and power meter) are shown in Fig. 3 (a) and (b), respectively.

3. Results of the Experiment

3.1. Vehicle usage

The vehicle usage of all participants is shown in Table 1. For the official vehicle, the distance traveled by the Elderly Care Division (Div-A) was 98 km in 10.5 days. The distance traveled by the Life Division (Div-B) was 330 km in 24.5 days, which was greater than that of the vehicle used by the Elderly Care Division. The vehicle usage time of the 11 individual participants varied from 7 to 15.5 days. Nine participants used the vehicle throughout a 7-day period. Two other participants used the vehicle over 8.5 and 15.5 days. The distance traveled by the 11 individual participants varied from 21 (1-D) to 271 km (1-F) and had a large variance. The total distance traveled by the two vehicles during the period of the social experiment (61 days) was 1,601 km.

Table 1. Vehicle usage of participants

| Veh. ID | Participant ID | Days | Distance (km) |
|---------|----------------|------|---------------|
| EV1     | Div-A          | 10.5 | 98            |
|         | 1-A            | 7    | 103           |
|         | 1-B            | 7    | 33            |
|         | 1-C            | 7    | 102           |
|         | 1-D            | 7    | 21            |
|         | 1-E            | 7    | 114           |
|         | 1-F            | 15.5 | 271           |
| Total of EV1 |               |      | 61 742 |
| EV2     | Div-B          | 24.5 | 330           |
|         | 2-A            | 7    | 38            |
|         | 2-B            | 7    | 105           |
|         | 2-C            | 7    | 219           |
|         | 2-D            | 7    | 78            |
|         | 2-E            | 8.5  | 89            |
| Total of EV2 |               |      | 61 859         |
| Total of EV1 and EV2 | |      | 122 1,601 |

3.2. Electricity consumption rate

The electricity consumption amount of the two electric vehicles (EV1 and EV2) during the experiment was 64.55 and 79.26 kWh, respectively. To investigate the electricity consumption related to the electric vehicle usage of each participant, they were required to record the power meter values and fully charge the electric vehicle before and after the experiment period. However, some participants forgot to record the electrical consumption or fully charge the vehicle, thereby making it difficult to accurately measure the electricity consumption amount of each participant.

Figure 4 shows the estimated electricity consumption rates of vehicles EV1 and EV2, which were estimated to be 87.0 and 92.3 Wh/km, respectively. The figure also shows the average
electricity consumption rate of the two vehicles, which was estimated to be 89.8 Wh/km.

3.3. Effect of CO2 reduction

To evaluate the effect of CO2 reduction through the use of ultra-compact electric vehicles, the CO2 emission amounts before and after adopting the ultra-compact electric vehicle were estimated for each participant. The CO2 emissions from the ultra-compact electric vehicle were based on the average electricity consumption rate 89.8 Wh/km and the vehicle distance traveled by each participant. Then, we applied the CO2 emission factor of 0.523 kg/kWh shown by the Kansai Electric Power Co., Ltd. in 2014 (7).

The CO2 emission amount before adopting the ultra-compact electric vehicle was estimated based on the fuel consumption rate reported by the participant and vehicle usage of the ultra-compact electric vehicle in the social experiment. It should be noted that one of the participants owned an electric vehicle before the adoption of the ultra-compact electric vehicles.

Based on the CO2 emission amounts before and after adopting the ultra-compact electric vehicle, we know that the CO2 emission reduction rate for all participants was 67% on average. The reduction rate of participants who owned gasoline cars varied from 53% to 79%. Meanwhile, the reduction rate for the participant who owned an electric vehicle was only 19%.

3.4. Effect of gasoline cost saving

Based on the fuel consumption before and after adopting the ultra-compact electric vehicle, we can estimate the overall gasoline cost saving rate for all participants and for individual participants. The participant owning a gasoline car could save 79%–89% of gasoline cost, whereas the participant who owned an electric vehicle could only save 20% of the gasoline cost. In this study, the prices of electricity and gasoline were set at 22 Yen/kWh and 160 Yen/L, respectively. We then estimated the annual gasoline cost saving amount for each participant (Fig. 5). We found that the gasoline cost saving amount varied from 9,000 to 86,000 Yen and had a large variance for the participants who owned gasoline cars. Meanwhile, the participant who owned the electric vehicle could only save 1,560 Yen annually.

4. Analysis of Running Characteristics

Since new test mode for the ultra-compact electric vehicles will be proposed in the next stage, analyzing its running characteristics and comparing them with gasoline cars is important. In this study, we compared the running characteristics of the ultra-compact electric vehicle and gasoline cars. The real-world running data for gasoline cars and the ultra-compact electric vehicle used in Kato City were used in this study.

4.1. Data and methodology

We used speed data for the ultra-compact electric vehicle collected in this social experiment, which were recorded by the GPS logger. Meanwhile, we used speed data collected by an engine control unit (ECU) logger for four gasoline cars taking part in an “eco-drive” activity in Kato City during the same period. The GPS logger device in this social experiment and the ECU logger device used in the eco-drive activity collected the speed data with the same frequency at 1-s intervals.

To investigate the running characteristics of two types of vehicles exactly, the data was aggregated by short trip. The short trip was defined here as the period starting from when the car begins moving and includes the period of stationary idling time until the car next begins moving (the beginning of the next short trip) or until the end of the trip. This method helped us to know the running characteristics in more detail than a method aggregated by long trip. The indexes maximal speed and average speed were both used in this study.

4.2. Results and discussion

Based on the calculation results shown in Fig. 6, we see that the distribution of average speed of the gasoline cars and that of the ultra-compact electric vehicles are similar, except when the average speed of gasoline cars is over 55 km/h, which indicates that the vehicle might have been traveling on the highway. Meanwhile, we can see that maximal speed of the ultra-compact electric vehicle is no more than 60 km/h in most cases, which might result from the fact that the design speed of the COMS used in the social experiment is no more than 60 km/h.
Figure 7 shows the mean of the maximal speed and average speeds of the vehicles used by the participants in the social experiment and eco-drive activity, respectively. The means of the maximal speed and average speed of ultra-compact electric vehicles are at the same level as gasoline cars. However, for most occasions, the means of the maximal speed and average speed of ultra-compact electric vehicles are lower than that of gasoline cars. This might indicate the following two facts: First, the design speed of gasoline cars is higher than that of ultra-compact electric vehicles. Second, a user driving an ultra-compact electric vehicle might not prefer an arterial road with a high speed limit, which might lead to the different running characteristic of the two types of cars.

5. Conclusions

This study investigated the electricity consumption properties of ultra-compact electric vehicles in the real world. The running data collected in a social experiment implemented in Kato City, Japan, were used for the empirical study. The following investigations were conducted: 1) the effects of CO2 reduction and gasoline cost savings from using an ultra-compact electric vehicle; 2) comparison of the running characteristics of gasoline cars and ultra-compact electric vehicles.

The major findings are listed as follows: First, the average electricity consumption rate of the COMS ultra-compact electric vehicle used in this study was 89.8 Wh/km. Therefore, the use of ultra-compact electric vehicles can reduce the CO2 emission amounts by 67%. Next, the gasoline cost savings amount for ultra-compact electric vehicles varies from 9,000 to 86,000 Yen annually, which indicates a larger variance because of the different distances traveled and vehicle type for each participant. Finally, the ultra-compact electric vehicles had lower maximal and average speeds than gasoline cars, which might have resulted from their design speed and the route choice and behavior of drivers.

Based on these major findings, we can conclude that the use of ultra-compact electric vehicles can dramatically reduce the CO2 emissions and gasoline cost savings amounts. However, this study only presents the results of participants living in Kato City; therefore, evaluating the effects of using ultra-compact electric vehicles by residents in other cities deserves further study. Meanwhile, the different running characteristics of gasoline cars and ultra-compact electric vehicles exist and were proved by this study. This will help us to understand how the ultra-compact electric vehicles can replace gasoline cars. Furthermore, it is suggested that new test mode for the ultra-compact electric vehicles corresponding to the JC08 mode for gasoline passenger vehicles is necessary in the next stage.

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