Evaluating Usability of a Battery Swap Station for Electric Two Wheelers

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Abstract This study aims to elicit individuals' perceived quality of use for the battery swap station (BSS). An experiment was conducted with a sample of 92 participants who had experienced a battery swapping service, operation procedure, and filled out a usability evaluation questionnaire for eliciting their agreement of learnability, efficiency, memorability, errors, and satisfaction. The results showed that the average operation time was approximately 2.32 min. 33 errors had been made by the 92 participants. Also, most of participants agreed with the quality of use for the proposed BSS, especially for the learnability, efficiency, and satisfaction. However, memorability and errors were important issues to be improved for the proposed BSS and should be investigated further.

Keywords Electric two wheelers (E2Ws) · Battery swap station · Usability · Usability evaluation

1 Introduction

The world is in the face of an energy shortage, environmental pollution, and global warming [1]. Road transport is responsible for a significant and growing share of global anthropogenic emissions of CO_2. Using oil-derived fuels in internal combustion engines generates tailpipe emissions of pollutants such as PM_{10}, NO_x, and VOCs, which are harmful to human health. Road transport is almost entirely dependent on oil-derived fuels. Decreasing CO_2 emissions is viewed as an important policy around the world [2]. Recently, the development of electric vehicles (EVs) has become more popular due to their contribution of alleviating the global energy crisis and reducing emissions [3]. The development of EVs relies on

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the charging patterns and available charging infrastructure, such as charging piles, charging station, and battery swap station (BSS) [4].

Taiwan has a population of 23 million, of which about 13.7 million are scooter users. Thus, one in every 1.67 people is a scooter commuter, which is the highest density in the world, and New Taipei City has the highest density in Taiwan. According to Taiwan's Environmental Protection Administration (EPA) report, emissions generated by scooters account for 330,000 tons of carbon monoxide and 90,000 tons of chemical compounds containing carbon hydroxide per year. The real-world operation of motorcycles/scooters results in a significant contribution of road transport CO and HC emissions, reaching 38 and 64 %, respectively, to the total emissions from road transportation [5]. In order to improve the air quality, the Taiwanese government is dedicated to promoting an eco-environmental protection policy. Increasing the penetration level of electric two wheelers (E2Ws) is one of the aims of the policy. The widespread adoption of E2W brings potential social and economic benefits, such as reducing the quantity of fossil fuels and greenhouse gas emissions, as well as environmental benefits. However, limitations on E2Ws batteries have meant that many people are unwilling to buy the related products. In spite of the incentives offered by Taiwan's government, the penetration level of E2W in the market is not encouraging. Only 29,942 e-scooters and 108,602 e-bikes were sold between 2009 and 2014.

A battery swapping model is proposed to overcome the battery limitations, including an expensive purchase price, short lifetime, limited driving range per charge, long charging time, and inconvenient charging, in order to improve the penetration of E2Ws in Taiwan. This model includes providing self-service battery swap stations (BSSs). The BSS, as one promising charging infrastructure, can provide great convenience to E2W customers without considering the all-electric range limit while the BSS is available. As of February 2014, there were 30 operational BSSs open to the public in New Taipei City, Taiwan. It is important to provide user-friendly BSS for E2W riders to enhance their willingness to accommodate related products and service. The purpose of this experimental study is to detect user external behaviors of operating the BSS, evaluate usability of BSS, and obtain the potential needs of E2W riders.

2 Literature Reviews

2.1 Battery Swapping System

A battery swapping model may provide a faster charging service than even the fastest recharging stations and lower the charging cost by charging depleted batteries overnight at a discounted electricity price. In this study, the battery swapping model separates the ownership of the battery and the E2W. Using a battery leasing service may also reduce the expense incurred by E2W owners. The model provides self-service BSSs, where an owner can ride to the nearest BSS and swap to a fully-charged battery within two minutes. BSS is one of the solutions to the limitations of the E2W battery [6–9]. The concept of an exchangeable battery service was first proposed as early as 1896 in order to overcome the limited operating range of electric cars and trucks [10]. BSS can also be regarded as energy-storage power stations, which can alleviate the variability and uncertainty of power output of renewable energy [11] and improve the management of a power grid [12]. BSS is usually connected to the megavolt-ampere scale substation [13] and requires high power during a day, which may lead to network overload. However, the charging load forecasting model for a BSS has not been included in [11–13], and the BSS is not simply a storage power plant which should also satisfy the battery swapping demand of E2Ws [11, 12].

BSS can offer great convenience for travel range that is longer than the driving range per charge of the vehicle. However, the BSS is not widely used due to the lack of standardization of batteries and interfaces. In this study, the battery swapping system comprises four industries: battery swapping system operators, E2W battery manufacturers, E2W manufacturers, and E2W retailers. In order to effectively integrate the industries and adopt the battery swapping system, battery certification specifications for E2Ws have been drafted to formulate a size standard for 48 V/10Ah–15Ah lithium-ion batteries, interchangeable interface standards to link batteries and vehicles, and a Taiwan E-scooter Standard (TES) for performance and safety. The draft was announced by Taiwan's EPA on December 9, 2013, to ensure the consistency of battery and vehicle quality. Here, E2Ws include electric scooters (e-scooter), electric bicycles (e-bike), and electric-assisted bicycles. According to E2W traffic laws, e-scooters are limited to 1000 W output, and cannot travel faster than 45 km/h on motor power alone on level ground. A driver's license and helmet are required to ride an e-scooter. E-bikes and electric-assisted bicycles cannot travel faster than 25 km/h. There is no lower age limit, so anyone can legally ride an e-bike or electric-assisted bicycles on roads. Furthermore, based on the swapping service availability, the construction cost of the system is the primary problem for investors.

2.2 Usability

The battery swapping system services require the support of the above-mentioned four industries. This highlights the importance of industrial integration and user acceptance for the battery swapping system. Moreover, system acceptability is the major issue addressed in this study. Nielsen's system acceptability model may provide an overview of the issues that influence the service acceptance of a system. Nielsen [14] defines acceptability as "whether the system is good enough to satisfy all the needs and requirements of the user." System acceptability is the goal designers should aim for and can be achieved by meeting the social and practical acceptability objectives of the system. Hence, the Nielsen system acceptability model is a combination of social acceptability and practical acceptability. With regard to practical acceptability, it is a combination of the characteristics of the system, including its usefulness, cost/price, compatibility, reliability.

Usefulness has been identified as a key objective of practical acceptability. Usefulness refers to how well a system achieves a desired goal, and is divided into two subcategories: utility and usability [15]. Utility is the question of whether that functionality in principle can do what is needed; usability is the question of how well users can use the functionality of a system [16]. The two concepts of usability and utility are highly interrelated. A usable user interface may contribute to a service being perceived as having the utility to provide appropriate functionality. Conversely, if a service has the utility to provide appropriate functionality, but can only be used or consumed via a badly designed user interface, users may avoid using the product or service.

With regard to the definition of usability, Bevan et al. [17] focus on how usability should be measured, with a particular emphasis on either ease of use or acceptability. The usability of a product is affected not only by the features of the product itself, but also by the characteristics of the users, the tasks they are carrying out, and the technical, organizational and physical environment in which the product is used [14]. Then, Nielsen [15] further defines a usable system as a quality attribute that assesses how easy user interfaces are to use, and outlines five usability attributes: learnability, efficiency, memorability, error recovery/few errors, and satisfaction. The definition of learnability is that “how easy is it for users to accomplish basic tasks the first time they encounter the design”. The definition of efficiency is that “once users have learned the design, how quickly can they perform tasks”. The definition of memorability is that “when users return to the design after a period of not using it, how easily can they reestablish proficiency”. The definition of errors is that “how many errors do users make, how severe are these errors, and how easily can they recover from the errors”. The definition of satisfaction is that “how pleasant is it to use the design”. The principles of usability are concerned with the five usability attributes, and are connected to the usefulness of a product. The International Organization of Standards (ISO) [18] defines usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use. Usability plays a role in each stage of the design process. Also, the only way to a high-quality user experience is to start usability evaluation early in the design process and to keep evaluation every step of the way. The outcome of a usability study is generally expected to be some recommendations on how to improve the product and how to make it easier and more enjoyable to use.

3 Methods

The BSS is self-service only. It is important to provide user-friendly BSS for E2W riders. This study forms investigation into user-based usability evaluation methods (UEM) based on experimental and survey studies for evaluating usability of the BSSs. The materials of the study are described as below:

1. Taiwan Electric Scooter Development Association (TESDA) provided 2 e-scooters for this study. It allowed experimental participants to have a real battery swapping experience at BSS. Each e-scooter with 2 batteries.
2. TESDA provided 1 BSS. It was located at Oriental Institute of Technology campus during the experimental period. The location of BSS is near the hospital, market, and MRT (Mass Rapid Transit) station. It was expected to recruit experimental participants easily and provide them to have a real battery swapping experience.
3. An experimental record form was developed to record each participant's operation time and errors for researchers. The operation time is that the total time participant spent in action was recorded from the start-up of scan ID card to the end of the second battery on the track removed to the E2W.
4. End-of-experiment subjective rating for BSS usability evaluation contained the following six sections—(1) personal information: three items designed to collect socio-demographic data on age (20–24, 25–34, 35–44, 45–54, 55–64, 65–74, and ≥ 75), sex (male and female), education (elementary, junior high, high school (senior), college, master's degree, and other), and occupation (student, industrial, commercial, service industry, teacher, and other); (2) learnability: five items designed to collect categorical quantitative data concerning interface, operational complexity, operation procedure, helpful information, and independently complete, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*; (3) efficiency: five items designed to collect categorical quantitative data concerning ID card sensor, confirm button, the use of the battery cover, remove batteries, and operational efficiency, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*; (4) memorability: three items designed to collect categorical quantitative data concerning assistance needs, needs of text information guide on the BSS interface, and operational efficiency, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*; (5) error recovery: five items designed to collect categorical quantitative data concerning the use of ID card, withdraw the track in a short term, re-operation, improper operation, and the need of voice guidance, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*; (6) satisfaction: four items designed to collect categorical quantitative data concerning BSS desing, operation procedure, battery weight, and system information, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*.
5. All of the participants have to complete the operation procedure of swapping 2 batteries for an e-scooter, after researcher introduced the experimental procedure

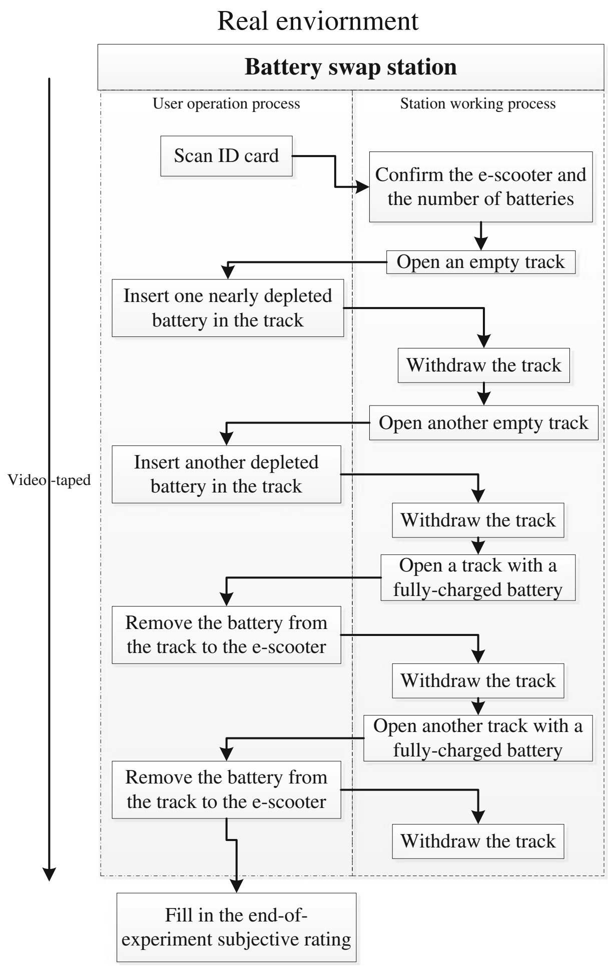

Fig. 1 Experimental procedure

which is shown in Fig. 1. During the term of swapping batteries for each participants, researcher record each participant's operation time and errors and video-taped. The key action to start swapping battery is to sense e-scooter's ID card on BSS. After the system conform the e-scooter's information, BSS may open an empty track for participant to insert battery in the track. After make user 2 batteries has been inserted in the BSS successfully, BSS may open a track with a fully-charged battery for participant to remove it from the track to the e-scooter. After 2 nearly depleted batteries has been exchange to the 2 fully-charged batteries, participant has to fill out the usability evaluation questionnaire.

The study was conducted over a month period on October 2014.

4 Results

Of 95 participants, 3 end-of-experiment subjective ratings involved material data omission, and the effective response rate was 96 %. For the 92 participants who completed the experiment and end-of-experiment subjective ratings, summarized data are shown in Table 1.

4.1 Descriptive Statistics

The average operation time to complete swapping batteries for the experimental participants was 138.96 s (σ = 38.24), amongst inserted 2 nearly depleted batteries in the track ($\bar{X}$ = 48.30 s, σ = 25.24) and removed 2 fully-charged batteries from the track to the e-scooter ($\bar{X}$ = 42.59 s, σ = 11.10). 33 errors were made by the participants, including the participants standard in the battery operation zone and caused BSS stopped working (18 times), putted battery on the BSS in the wrong direction or position (9 times), and could not find where to scan the ID card (6 times). During the experimental period, 4 times abnormal operation of the BSS were happened. With regard to usability evaluation, the most agreed factor of usability for participants was efficiency ($\bar{X}$ = 4.31, σ = .73), followed by learnability ($\bar{X}$ = 3.91, σ = .53), satisfaction ($\bar{X}$ = 3.9, σ = .77), and memorability ($\bar{X}$ = 3.49, σ = .53). Most of participants were not agreed that the BSS may support them to avoid errors or to recover from the errors ($\bar{X}$ = 2.50, σ = .58).

Table 1 Demographic information of the participants (N = 92)

Items		Frequency (n) and sequence					
		1	2	3	4	5	6
Gender	Item Total %	Male 65 (70.7)	Female 27 (29.3)				
Age	Item Total %	20–24 73 (79.3)	25–34 12 (13.0)	35–44 4 (4.3)	45–54 2 (1.1)	55–64 1 (2.2)	
Education	Item Total %	College 72 (78.3)	Senior 10 (10.9)	$\geq$ Master 8 (8.7)	Junior 2 (2.2)		
Occupation	Item Total %	Student 67 (72.8)	Industrial 6 (6.5)	Service industry 5 (5.4)	Commercial 5 (5.4)	Other 5 (5.4)	Teacher 2 (2.2)

4.2 t Test

The dependent samples t-test results indicated that operation time differed significantly (p = .032) between inserted 2 nearly depleted battery in the track (=48.30 s, $\sigma = 25.24$) and removed 2 fully-charged batteries from the track to the e-scooter ($\bar{X} = 42.59$ s, $\sigma = 1.55$).

The t -test results indicated that the needs of text information guide on the BSS interface differed significantly ($t = 3.05$, $p = .004$) between men ($\bar{X} = 3.75$, $\sigma = 1.05$) and women ($\bar{X} = 2.93$, $\sigma = 1.24$).

4.3 Correlation Analysis

The correlation analysis results showed that efficiency was positively correlated with learnability ($r = .529$, $p < .01$), memorability ($r = .294$, $p < .01$), and satisfaction ($r = .496$, $p < .01$). Efficiency was negatively correlated with errors ($r = -.359$, $p < .01$). With regard to the errors, it were negatively correlated with learnability ($r = -.266$, $p < .05$), efficiency ($r = -.359$, $p < .01$), and satisfaction ($r = -.282$, $p < .01$), and was positively correlated with memorability ($r = .224$, $p < .05$). With regard to the momorability, it were positively correlated with learnability ($r = .372$, $p < .01$), efficiency ($r = .294$, $p < .01$), and errors ($r = .224$, $p < .05$). With regard to the learnability, it were positively correlated with efficiency ($r = .529$, $p < .01$), momorability ($r = .372$, $p < .01$), and satisfaction ($r = .589$, $p < .01$), and was negative correlated with errors ($r = -.266$, $p < .05$). With regard to the satisfaction, it were positively correlated with learnability ($r = .589$, $p < .01$) and efficiency ($r = .496$, $p < .01$), and were negatively correlated with errors ($r = -.282$, $p < .01$).

5 Discussion

The average operation time for e-scooter riders to accomplish swapping batteries by using the proposed BSS was approximately 2.32 min. In addition, the average operation time for users to accomplish inserting 2 nearly deleted batteries in the track was approximately 48.3 s. The average operation time for users to accomplish remove 2 batteries from the track to the e-scooter was approximately 42.59 s. It also showed a significant learning effect for using the self-service BSS. However, several usability problems had been found and need to be improved in the near future.

The important problems caused users making errors were improper BSS designs, including sensing zone, battery track, and ID sensor zone. With regard to sensing zone design, it was designed to avoid pinched user when the track is withdrew.

However, the designed distance between BSS and user is too long distance. It was limited by the battery size and the track design. It also leaded that BSS users have to go back 1or 2 steps after insert or remove battery for the station continuing operation. With regard to battery track design, 9 participants insert the battery with wrong direction. Furthermore, the battery track design is limited by battery size and design. Finally, results showed that 6 participants could not find where to sense the ID card. Although the errors participants made were easily to recover, and the error rate is not high (35.9 %), the results of the usability evaluation displayed that the only one factor participants not agreed was errors ($\bar{X}$ = 2.50, σ = .58). In addition, 4 times malfunctions of track open or withdraw happened during the experimental period. These may highlight the important of battery design, remove and insert battery design, and BSS reliability.

Most of participants agreed with the BSS design may meet their needs of efficiency, learnability, and satisfaction. Results of usability evaluation also showed users need more memory resources to accomplish swapping batteries caused more errors been made. Moreover, male needed more text information guide on BSS then female did. It showed that users require real-time operating instructions to assist them complete all tasks.

6 Conclusion

In this study, an experiment and a survey of usability evaluation were conducted to find participant's operation time and errors of using the proposed BSS and elicit their feedback of quality of using BSS including learnability, efficiency, memorability, error recovery/few errors, and satisfaction. The results of current study indicate that users may complete swapping batteries in approximately 2.32 min by using the proposed BSS. The BSS may provide a nice learning effect. Most of participants agreed with quality of using BSS, including learnability, efficiency, and satisfaction. However, memorability and errors need to be improved. In order to increase the quality of use for the proposed BSS, memorability, errors, and re-design battery and BSS should be investigated further.

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