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Research Article

Analysis of Mutual Influence Relationships of Purchase Intention Factors of Electric Bicycles: Application of DEMATEL Taking into Account Information Uncertainty and Expert Confidence

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As the negative environmental impacts of transportation systems become more severe, governments and environmental groups are seeking more sustainable transportation options, such as replacing fuel-powered vehicles with electric vehicles and expanding public transportation systems to reduce the number of people driving on their own, in order to reduce the environmental impacts of transportation systems. At present, the rapid expansion of public transportation systems is not an easy task and requires a long period of time to plan for expansion and construction, so people are increasingly looking to find means of transportation that meet sustainable conditions as solutions. In this context, electric bicycles are one of the solutions that people can choose, with benefits such as energy saving, carbon reduction, effective air pollution reduction, and simple and labor-saving riding. However, in Taiwan, despite the many benefits of electric bicycles, their popularity is not high. Therefore, this study focuses on the factors that affect the purchase of electric bicycles in Taiwan. The Influential Network Relation Map (INRM) generated by the *Z*-based Decision-making Trial and Evaluation Laboratory (*Z*-DEMATEL) technique is used to describe the influence relationships among the factors and to establish the key evaluation criteria of electric bicycle purchase intention. The results indicate that vehicle price, safety, motor performance, battery life, and battery durability are the most important factors in purchasing electric bicycles. Furthermore, the power of motor is considered as the factor that most significantly affects other criteria, while safety and price are most likely to be affected by other criteria. This study has contributed to academia and industry, for the dependency weights of these factors are set to provide a scientific and systematic way to show how consumers think in the decision-making process and to provide more reliable information and management implications for the electric bicycle industry.

1. Introduction

Since the twentieth century, the world has been facing environmental pollution problems caused by harmful emissions from conventional fuels, such as hydrocarbons, nitrogen oxides, carbon monoxide, and suspended particulates, due to advances in transportation and communication technologies resulting in the proliferation of public transportation vehicles [1]. As environmental protection issues have gained attention and awareness of the energy crisis has risen, countries around the world have developed sustainability agreements such as the Sustainable Development Goals (SDGs) and the Convention on Biological Diversity (CBD) to persuade companies to move

toward sustainable development. The purpose of sustainable development is "to meet people's needs and future development while maintaining environmental balance and sustainability in the direction of investment, technological development, resource development, and institutional change, with benefits that meet societal expectations" [2].

More than 128 countries in the world have declared that they will achieve "net-zero carbon emissions" by 2050, hoping to effectively reduce carbon emissions to achieve net-zero carbon emissions [3, 4]. Governments around the world have begun to formulate improvement plans for transportation, looking for sustainable public transportation that reduces environmental pollution and low energy consumption, and are actively moving toward the goal of achieving zero carbon emissions in transportation [1]. Sustainable electric vehicles are considered to have a significant positive impact on the environment, effectively replacing traditional gasoline and diesel vehicles that cause serious environmental pollution, for example, by reducing air pollution and noise [5–8]. The awareness of sustainability has led to a boom in electric vehicle manufacturing-related industries, among which electric bicycles have become the mainstream focus of today's green transportation [9].

In recent years, electric bicycles have been the fastest growing industry in the transportation market [10, 11], especially in highly congested urban areas, where they are more comfortable than other eco-transit vehicles such as conventional bicycles. Compared with automobiles and motorcycles, electric bicycles have relatively low purchase cost and convenience for short-distance travel, which increases the overall demand in urban areas and makes electric bicycles the preferred means of transportation for the public [12, 13]. According to the Confederation of the European Bicycle Industry (CONEBI), more than 22 million electric bicycles have already been sold in Europe in 2020, generating a value of over 18.3 billion Euros, a significant 40% increase in electric bicycle sales compared with 2019. In the United States, the epidemic has created a huge demand for personal commuting. With the difficulty of predicting when the epidemic will abate, and with the government discouraging public transportation, American commuters are turning their attention to convenient electric bicycles [14]. The United States Department of the Interior in October 2018 announced that electric bicycles could be ridden on regular bicycle trails, etc., which boosted the public's willingness to buy electric bicycles, and gradually increased the demand for electric bicycles in the United States (U.S.) market. In urban transportation systems in Europe and the U.S., the increasing reliance on the role of electric bicycles with the use of renewable energy sources has led to their widespread use [11, 15]. Governments have also been liberalizing the use of electric bicycles in public spaces, and electric bicycles are often legally defined as bicycles, and therefore face less oversight and regulation than gasoline-powered models [16].

In response to this trend, electric bicycles are more in short supply in the market. Taiwan is the kingdom of producing bicycles and electric bicycles, so the sales of bicycles and electric bicycles in Taiwan have been increasing. Electric bicycles are in line with the trend of sustainable development with the advantages of energy saving and carbon reduction which can effectively reduce air pollution, boost simple and effortless riding without a driver's license It is gradually becoming the new choice of human mobility. Electric bicycles are regarded as the rising star of the bicycle industry [17]. Electric bicycles have a speed limit of 24 km/h, which can avoid speeding, and is more secure for the elderly in terms of speed control and safety. In addition, compared with electric motorcycles/scooters, they are exempt from license tax and the riders' helmets are not required in Taiwan. These are all beneficial to the future of electric bicycles. Besides, the Taiwan government is also actively promoting the relevant subsidy policies for the purchase of electric bicycles. Therefore, the research objectives can be described as follows.

(i) Firstly, it is to explore the purchase intention factors of electric bicycles in Taiwan, and which reasons are the main considerations of electric bicycle purchase in Taiwan, so as to establish the purchase intention factors.

(ii) Next, what is the importance of each of these purchase intention factors? What is their ranking?

(iii) Besides, what are the mutual influence relationships among the purchase intention factors?

The above questions are typical Multiple Criteria Decision-Making (MCDM) issues. The MCDM methodologies are effective in dealing with multiple complex and constrained criteria, and it is possible to identify criteria weights through expert interviews and soft computing techniques. MCDM overcomes several assumptions in the use of traditional statistical theory (e.g., the sample data needs to conform to a normal distribution, and the assumption that variables are independent of each other). MCDM allows the use of a small sample of expert interview data to generate reliable analytical results through consistency or consensus testing [18–20]. In this study, we have three main implementation stages. The first stage is to propose a framework for evaluating electric bicycle purchase intention factors in a model that aggregated 10 main purchase intention factors through extensive literature and expert interviews. In the second stage, the Z-based Decision-making Trial and Evaluation Laboratory (Z-DEMATEL) [21] is used to identify the mutual influence relationships of the intention factors and generate dependency weights. This technique not only takes into account the uncertainty of the information sources, but also measures the reliability of the experts in the evaluation. In the third stage, the Influential Network Relation Map (INRM) is plotted to present visualized results to discuss management implications and give appropriate strategies for decision-makers to follow.

Common weight determination methods include Analytic Hierarchy Process (AHP) [22], Best-Worst Method (BWM) [23], Full Consistency Method (FUCOM) [24], Level-Based Weight Assessment (LBWA) [25], Interpretative Structural Modeling (ISM) [26], DEMATEL [27], etc. These methods are popular and frequently used [28].

However, some methods, such as AHP, BWM, FUCOM, and LBWA, treat the criteria as independent. In other words, they assume that the criteria do not interact with each other. Such an assumption is not in line with the actual situation. On the contrary, DEMATEL is a technique for identifying criteria dependencies, which improves the shortcomings of ISM, for it can only identify influence with variables 0 and 1. DEMATEL has been widely used in various industries to evaluate the dependence of factors, and many studies have confirmed its effectiveness and usefulness [29–33]. On the other hand, in order to effectively conduct an evaluation in an uncertain environment and measure the confidence of experts in evaluation, this article introduces Z sets theory to replace the general fuzzy theory. Z-DEMATEL is different from other fuzzy DEMATEL techniques (e.g., general fuzzy DEMATEL, intuitionistic fuzzy DEMATEL, Pythagorean fuzzy DEMATEL, and Fermatean fuzzy DEMATEL), which constructs the confidence of experts by integration, and then combines the confidence into the fuzzy evaluation value, so that the evaluation value covers a wider range of information. Many studies have confirmed the practicality of Z sets theory [21, 34].

This study takes the development of electric bicycles in Taiwan as an example and invites experts from the electric bicycle industry, cultural and creative industries, and government agencies to form a decision-making team to use their experience and skills as the basis for data construction. The study scientifically and systematically shows the decision thinking of electric bicycle purchase intention and provide more reliable information and management implications for electric bicycle operators. The specific features and contributions of this article are summarized as follows.

(i) This study adopts the MCDM concept to construct a framework for evaluating the purchase intention factors of electric bicycles.

(ii) DEMATEL-based approach is used to identify the influential relationship among the factors and their influence weights.

(iii) The introduction of Z sets theory reflects uncertainty and expert confidence.

(iv) The research is reproducible. Other products or industries can be analyzed following the same research process.

The rest of the article is organized as follows: Section 2 introduces the literature review of electric bicycle purchase intention and identifies the criteria for electric bicycle purchase intention evaluation. Section 3 describes the basic concepts of Z-numbers and illustrates the Z-DEMATEL calculation process. Section 4 introduces the case study and discussion of electric bicycle purchase intention in Taiwan and presents the feasibility and practicality of the proposed model. Section 5 concludes

the full discussion and gives conclusions, and finally provides future research directions.

2. Literature Review

This section presents the literature on electric bicycle intentions and describes the proposed framework.

2.1. Electric Bicycle Purchase Intention. With global warming, the awareness of sustainable transportation for energy saving and carbon reduction has been increasing day by day. The use of electric bicycles is growing steadily around the world. Electric bicycles are a relatively environmentally friendly means of transportation, especially for short to medium distances, the use of electric bicycles can help reduce traffic congestion [1, 5]. Numerous studies have contributed to the electric bicycle purchase intention [35–40].

For example, Bigazzi and Berjisian [35] explored the impact of government incentives on electric bike purchase intentions. Considerations include product price, demand, subsidies, and the allowable price elasticity for consumers. The results show that incentive policies can actually improve consumers' purchase intention. Sałabun et al. [13] used the Characteristic Objects Method (COMET) to discuss the relationship between electric bike features and purchase intention. The evaluation factors include battery capacity, battery charging time, number of gears, vehicle weight, price, etc. In the following year, Shekhovtsov et al. [36] used the same evaluation factors to select different types of e-bikes. Simsekoglu and Klöckner [37] took Norway as an example to study the indicators that affect the intention to buy electric bicycles, which considers factors including age, gender, experience, benefits, safety, environment, etc. Their study applied multiple regression and principal component analysis to identify the influence of indicators. The results show that age, benefits, other people's opinions, and familiarity significantly influence purchase intent. Herberz et al. [40] pointed out that most consumers agree to use environmentally friendly means of transportation. Their study used regression models to measure the impact of environmental factors on electric bike purchase intentions. Emitting less carbon dioxide, reducing the potential damage to the environment, and being environmentally friendly are important factors when people purchase an electric bike.

Most of the above literature uses statistical methodology as an analytical tool. Few studies have explored the interaction of purchase intention with the concept of MCDM. Beyond that, they have not considered the uncertainty of the assessment environment. In order to overcome the above-mentioned issues, this study uses Z-DEMATEL to effectively identify the relationship among factors, and determine the confidence of experts in the assessment. We reviewed the extensive literature and integrated the judgments of multiple

experts to construct an evaluation framework. Section 2.2 presents the proposed factors and their definitions.

2.2. Proposed Framework. Based on past academic literature and discussions among experts from industry, government, and academia, the initial evaluation factors of electric bicycle purchase intention were established and the more important criteria were selected to be included in the evaluation system to highlight the characteristics and meaning of electric bicycle purchase intention. The main factors consist of 10 criteria, including price (C_1), battery life (C_2), battery durability (C_3), charging time (C_4), power of motor (C_5), and external influences are after-sales service (C_6), infrastructure (C_7), safety (C_8), government regulations (C_9), and government policy (C_{10}).

Price (C_1) aims to measure the reasonable price of electric bicycles that consumers can accept, and to increase consumers' purchase intention by setting a reasonable selling price [13, 35, 36]. In addition to price, the battery of an electric bicycle is the main source of power supply for the vehicle, and battery life (C_2), battery durability (C_3), charging time (C_4), and power of engine (C_5) are included in the evaluation framework. Battery life (C_2) evaluates the time from good to bad during battery use. Repeated charging of batteries may cause shortened battery life. If there is good research and development (R&D) technology or patents, it will extend the battery life and increase the intention of consumer consumption [13, 36]. Battery durability (C_3) evaluates the distance that a single charge of the battery can be ridden. Under normal riding conditions, the higher the battery durability, the longer the riding distance, and the more beneficial it is to reduce the number of battery recharges [13, 36, 38]. Charging time (C_4) mainly evaluates the time required to charge the vehicle battery from no power at all to a full charge. Besides, the length of charging waiting time affects the convenience of reusing the electric bicycle [13, 36]. Finally, power of engine (C_5) evaluates the performance of the vehicle's power, whether it provides a high-performance motor with multiple functional modes to meet the needs of consumers in any situation [13, 36].

This study not only discusses the performance of the electric bicycle itself, but also discusses external influences, mainly evaluating the influence of various factors in the external environment on the purchase intention. Among the factors, after-sales service (C_6) aims to evaluate the services related to the purchase of the electric bicycle, including warranty, repair and maintenance, etc., to protect the consumer's rights after the purchase with the help of comprehensive after-sales service. Infrastructure (C_7) examines whether there is a well-planned electric bicycle system that provides a good cycling environment for riders, as well as convenient charging facilities, battery swapping stations, and repair shops [39, 40]. Safety (C_8) aims to measure the safety of road traffic, the lives of riders operating electric bicycles, the availability of adequate safety regulations, manuals, and

TABLE 1: Evaluation scales of Z-DEMATEL and corresponding membership functions [21].

Linguistic variable (F, R)	Z-numbers
(N, VL)	(0, 0, 0.316)
(N, L)	(0, 0, 0.548)
(N, M)	(0, 0, 0.707)
(N, H)	(0, 0, 0.837)
(N, VH)	(0, 0, 0.949)
(L, VL)	(0, 0.316, 0.632)
(L, L)	(0, 0.548, 1.096)
(L, M)	(0, 0.707, 1.414)
(L, H)	(0, 0.837, 1.673)
(L, VH)	(0, 0.949, 1.897)
(M, VL)	(0.316, 0.632, 0.949)
(M, L)	(0.548, 1.096, 1.644)
(M, M)	(0.707, 1.414, 2.121)
(M, H)	(0.837, 1.673, 2.510)
(M, VH)	(0.949, 1.897, 2.846)
(H, VL)	(0.632, 0.949, 1.265)
(H, L)	(1.096, 1.644, 2.192)
(H, M)	(1.414, 2.121, 2.828)
(H, H)	(1.673, 2.510, 3.347)
(H, VH)	(1.897, 2.846, 3.795)
(VH, VL)	(0.949, 1.265, 1.265)
(VH, L)	(1.644, 2.192, 2.192)
(VH, M)	(2.121, 2.828, 2.828)
(VH, H)	(2.510, 3.347, 3.347)
(VH, VH)	(2.846, 3.795, 3.795)

the riding environment [40]. The last two are government regulations (C_9) and government policy (C_{10}) for examining whether the government has adequate regulations to protect the right to purchase electric bicycles and whether the government provides incentives and subsidies to encourage consumers to purchase electric bicycles [35].

3. Research Approach

The research approach used in this article is based on the Z-DEMATEL proposed by Hsu et al. [21] for data analysis. In this section, the basic concepts of Z-numbers are first introduced and the conversion rules of the linguistic variables, which overcome the shortcomings of fuzzy theory sets by increasing the reliability measure for experts in the evaluation, so that uncertain information can be described more clearly. Then, the detailed calculation procedure of Z-DEMATEL is given and the INRM is plotted to present the mutual influence relationships of the purchase intention factors. And this can help the decision-makers to quickly identify the main factors of the electric bicycle purchase intention.

3.1. Concepts of Z-Numbers and Conversion Rules for Linguistic Variables. Zadeh [41] proposed a method of augmenting fuzzy theory called Z-number, which consists of two fuzzy parameters, one for the uncertainty of the evaluated information and the other for the reliability of the

expert at the time of evaluation. A Z-number can be denoted as $Z = (\widetilde{F}, \widetilde{R})$, where $\widetilde{F}$ is the rating given by the expert in the evaluation event and $\widetilde{R}$ is the reliability given $\widetilde{F}$. Both $\widetilde{F}$ and $\widetilde{R}$ are triangular fuzzy numbers with a value range between 0 and 1, and $\widetilde{F}$ and $\widetilde{R}$ can be written as $\widetilde{F} = (f, \mu_{\widetilde{F}}) | x \in [0,1]$ and $\widetilde{R} = (x, \mu_{\widetilde{R}}) | x \in [0,1]$. In the Z-number processing program, $\widetilde{R}$ (reliability) can be converted into a crisp value, as shown in (1).

$$\alpha = \frac{\int^x \mu_{\widetilde{R}} dx}{\int^{\mu_{\widetilde{R}}} dx}.$$ (1)

Next, the reliability weight α is added to the evaluated value $\widetilde{F}$. The weighted Z-numbers are as in (2).

$$Z^\alpha = \left\{ \left(x, \mu_{\widetilde{F}^\alpha} \right) | \mu_{\widetilde{F}^\alpha}(x) = \alpha \mu_{\widetilde{F}}(x), x \in \sqrt{\alpha} \, x \right\}.$$ (2)

Here, it is assumed that an evaluation system has n criteria/alternatives, $c_i = (c_1, c_2, \ldots, c_n)$. For these criteria/alternatives, pairwise comparisons must be conducted to explore the mutual influence, i.e., to evaluate the degree of influence of c_i on c_j. The evaluation scales include "No influence (N)," "Low influence (L)," "Medium influence (M)," "High influence (H)," and "Very high influence (VH)." These linguistic variables are converted into the corresponding membership functions (fuzzy numbers). Next, the experts are asked to evaluate the level of confidence in their answers, i.e., the reliability of the evaluation. The evaluation scales include "Very low (VL)," "Low (L)," "Medium (M)," "High (H)," and "Very high (VH)." Therefore, a total of 25 combinations of Z-numbers can be obtained, and in the same way, the linguistic variables of Z-numbers and their membership functions can be obtained, as shown in Table 1.

3.2. Z-DEMATEL Technique.
The DEMATEL technique identifies the mutual influence relationships between factors and helps decision-makers understand which factors are the primary affecting factors on others and which are the affected factors by others through a structured INRM [42]. In an evaluation environment that is complex and full of uncertainties, it is difficult for the experts to use crisp values to reflect their true feelings. Many fuzzy theoretical approaches have been combined with DEMATEL to consider uncertainties, but unfortunately, these approaches ignore the degree of confidence that the experts have in their evaluations. In this study, Z-numbers are introduced into DEMATEL to not only know the reliability of the decision-making team in the evaluation, but also to preserve the triangular fuzzy number form for computation to avoid information loss. Through the improvement of this study, the influential weights of a set of criteria/factors can be obtained by Z-DEMATEL, and the detailed steps of the Z-DEMATEL technique are as follows.

Step 1. Develop a set of evaluation criteria/factors

A group of experts formed a decision-making team to develop a set of appropriate evaluation criteria/factors (c_i). In this study, we consider the factors of development trends as criteria, $c_i = \{c_1, c_2, \ldots, c_n\}$.

Step 2. Build the direct relation matrix **A** of the group

Here, there are n development factors that need to be evaluated for their influence. Each expert evaluates the degree of direct influence of the factor i on the factor j and measures the expert's confidence in the rating. This step introduces the concept of Z-numbers into the Z-DEMATEL questionnaire.

The opinions of all experts are averaged to integrate a group of direct relation matrix **A**, as shown in equation (3).

$$\mathbf{A} = \left[Z(a_{ij}) \right]_{n \times n}$$

$$= \begin{bmatrix} Z(a_{11}) & Z(a_{12}) & \ldots & Z(a_{1j}) & \ldots & Z(a_{1n}) \\ Z(a_{21}) & Z(a_{22}) & \ldots & Z(a_{2j}) & \ldots & Z(a_{2n}) \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ Z(a_{i1}) & Z(a_{i2}) & \ldots & Z(a_{ij}) & \ldots & Z(a_{in}) \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ Z(a_{n1}) & Z(a_{n2}) & \ldots & Z(a_{nj}) & \ldots & Z(a_{nn}) \end{bmatrix}_{n \times n},$$ (3)

$$i = j = 1, 2, \ldots, n,$$

where $Z(a_{ij}) = (a_{ij}^L, a_{ij}^M, a_{ij}^U)$.

Here, Z-DEMATEL requires the diagonal elements in matrix **A** to be 0, i.e., $Z(a_{ij}) = 0$ (when $i = j$).

Step 3. Obtain the normalized direct relation matrix **X**

Since the range of values of $Z(a_{ij})$ is 0 to 4, we can convert this evaluation to 0 to 1 through normalization (4) and (5).

$$\mathbf{X} = \left[Z(x_{ij}) \right]_{n \times n} = \varepsilon \cdot \left[Z(a_{ij}) \right]_{n \times n},$$

$$i = j = 1, 2, \ldots, n,$$ (4)

where $Z(x_{ij}) = (x_{ij}^L, x_{ij}^M, x_{ij}^U)$.

$$\varepsilon = \min \left\{ \frac{1}{\max_i \sum_{j=1}^n a_{ij}^U}, \frac{1}{\max_j \sum_{i=1}^n a_{ij}^U} \right\}.$$ (5)

Step 4. Generate the group total influence matrix **T**

The normalized direct relation matrix **X** (4) can be integrated into a total influence matrix **T** by the computation of (6). This step sums up all direct and indirect influence relationships from the power of **X** to the power of infinity. Since the operation procedure of (7) is cumbersome, a faster solution equation can be derived from (8).

$$\mathbf{T} = \left[Z(t_{ij}) \right]_{n \times n},$$

$$i = j = 1, 2, \ldots, n,$$ (6)

where $Z(t_{ij}) = (t_{ij}^L, t_{ij}^M, t_{ij}^U)$.

$$\mathbf{T} = \mathbf{X} + \mathbf{X}^2 + \cdots + \mathbf{X}^{\infty}, \tag{7}$$

$$\begin{aligned} \mathbf{T} &= \mathbf{X} + \mathbf{X}^2 + \cdots + \mathbf{X}^{\infty} = \mathbf{X}\left(\mathbf{I} + \mathbf{X} + \mathbf{X}^2 + \cdots + \mathbf{X}^{\infty-1}\right) \\ &= \mathbf{X}\left(\mathbf{I} - \mathbf{X}^{\infty}\right)\left(\mathbf{I} - \mathbf{X}\right)^{-1} \\ &= \mathbf{X}\left(\mathbf{I} - \mathbf{X}\right)^{-1}, \end{aligned} \tag{8}$$

where $\mathbf{X}^{\infty} = [0]_{n \times n}$ and $\mathbf{I}$ is the unit matrix.

Step 5. Create an INRM to identify the mutual influence relationships of the development factors

In (9) and (10), $Z(\mathbf{r})$ is obtained by summing up each column of the total influence matrix $\mathbf{T}$. Similarly, in (11) and (12), $Z(\mathbf{s})$ is obtained by summing up each row of the total influence matrix $\mathbf{T}$.

$$\begin{aligned} Z(\mathbf{r}) &= [Z(r_i)]_{n \times 1} \\ &= (Z(r_1), Z(r_2), \ldots, Z(r_i), \ldots, Z(r_n)), \end{aligned} \tag{9}$$

$$[Z(r_i)]_{n \times 1} = \left[\sum_{j=1}^{n} Z(t_{ij})\right]_{n \times 1}, \tag{10}$$

$$\begin{aligned} Z(\mathbf{s}) &= [Z(s_j)]_{1 \times n} \\ &= (Z(s_1), Z(s_2), \ldots, Z(s_j), \ldots, Z(s_n))^T, \end{aligned} \tag{11}$$

$$\begin{aligned} [Z(s_j)]_{1 \times n} &= \left[\sum_{i=1}^{n} Z(t_{ij})\right]_{1 \times n} \\ &= [Z(s_i)]_{n \times 1}^T, \end{aligned} \tag{12}$$

where the symbol "superscript T" represents the matrix transposition, in addition, $Z(r_i) = (r_i^L, r_i^M, r_i^U)$ and $Z(s_i) = (s_i^L, s_i^M, s_i^U)$.

$Z(r_i) + Z(s_i)$ is the index of the strength of influences given and received. On the other hand, $Z(r)_i - Z(s_i)$ represents the net influence; the larger the $Z(r_i) + Z(s_i)$, the greater the degree of influence of factor i on the evaluation system. If $Z(r)_i - Z(s_i) > 0$ (a positive value), it means that factor i has a significant effect on other factors and is called a causal factor; conversely, if $Z(r)_i - Z(s_i) < 0$ (a negative value), it means that factor i is more affected by other factors and is called an affected factor.

Here, the centroid method is used to defuzzify fuzzy values (e.g., $Z(\lambda) = (\lambda^L, \lambda^M, \lambda^U)$) to obtain the crisp values (λ), as in (13).

$$\lambda = \frac{\lambda^L + \lambda^M + \lambda^U}{3}. \tag{13}$$

Next, r_i and s_i are obtained for $Z(r_i)$ and $Z(s_i)$ by the defuzzification procedure of (13). The relative coordinate positions of each factor are clearly plotted by using $r_i + s_i$ as the horizontal axis and $r_i - s_i$ as the vertical axis. The total influence matrix $\mathbf{T}$ is used to identify the influence between each factor, and the arrows (indicating the direction of influence) are plotted to generate a systematic INRM.

Step 6. Obtain the influence weights of the development factors

Here, $r_i + s_i$ reflects the total influence of the factors on the evaluation system, so the influence weights $w_i = \{w_1, w_2, \ldots, w_n\}$ of the factors can be constructed by (14). Here, the total weight is required to be 1.

$$w_i = \frac{(r_i + s_i)}{\sum_{i=1}^{n}(r_i + s_i)}. \tag{14}$$

4. Empirical Analysis and Results

This section introduces the background of the case, the data collection process, and the *Z*-DEMATEL implementation procedure.

4.1. Background Description and Data Collection. Nowadays, the public is gradually aware of the importance of air quality, causing the gradual elimination of gas and diesel from public transportation systems and the active use of non-emission electric systems. The most common means of transportation, such as trains, buses, automobiles, motorcycles/scooters, and bicycles, have been gradually transformed to be powered by electric systems. Especially in recent years, with the development of electric bicycles, they have gradually become one of the new transportation options in Taiwan because of their high energy efficiency, high power, and license exemption. Although electric bicycles have the advantage of less environmental pollution, they are not yet as popular as motorcycles/scooters in Taiwan. In order to investigate the related problems, this study uses a literature review to establish the criteria related to electric bicycles assessing what causes the low popularity of electric bicycles? What are the reasons that affect consumers' willingness to purchase electric bicycles? What are the most critical and likely factors that influence consumers' purchase intentions? How do the criteria influence each other? The answers to these questions will help improve the business model of electric bicycle operators and increase the popularity of electric bicycles in Taiwan. Therefore, in order to identify the most critical criteria in electric bicycles, this study invited 15 experts in the electric bicycle industry to form an expert team, who come from academic researchers, industry department heads, and senior industry employees, all of whom have expertise in electric bicycles. The study compiles the background information of the 15 experts and presents the results in Table 2.

In this study, structured interviews were conducted in a face-to-face format. The advantages of structured interviews are as follows: the entire interview process is highly

TABLE 2: Background introduction of 15 experts.

Expert code	Industry	Work experience	Highest degree
Expert 1	Academic research institutes	10 years or more	PhD
Expert 2	Academic research institutes	5–10 years	PhD
Expert 3	Bicycle manufacturing	More than 10 years	Associate bachelor
Expert 4	Bicycle manufacturing	More than 10 years	Master
Expert 5	Bicycle manufacturing	More than 10 years	Bachelor
Expert 6	Electric vehicle manufacturing	5–10 years	Associate bachelor
Expert 7	Recreational sports industry	2–3 years	Bachelor
Expert 8	Recreational sports industry	More than 10 years	Master
Expert 9	Bicycle components manufacturing	2–3 years	Bachelor
Expert 10	Bicycle components manufacturing	More than 10 years	Bachelor
Expert 11	Transportation-related ministries	2–3 years	Master
Expert 12	Transportation-related ministries	More than 10 years	Master
Expert 13	Transportation-related ministries	4–5 years	Master
Expert 14	Energy-related ministries	3–4 years	Associate bachelor
Expert 15	Energy-related ministries	10 years or more	Bachelor

standardized, the return rate of the questionnaire is higher, and the responses are more complete. These facilitate subsequent recording and analysis. In this study, 15 experts were invited to an office of the company to explain the survey process. First, all experts were asked to sign a consent form to ensure that the experts' basic information and survey results would not be leaked. Next, the meaning of each criterion was explained and the process of filling out the Z-DEMATEL questionnaire was presented. The presentation and demonstration of the questionnaire content took 15 minutes, and the average time for the experts to complete the questionnaire was 60 minutes, for a total of approximately 75 minutes for one questionnaire.

4.2. Z-DEMATEL Implementation. After collecting Z-DEMATEL questionnaires from 15 experts, to ensure a high degree of consistency among the experts' responses, this study used the consensus check formula used by Hsu et al. [21] to calculate the consensus among experts' responses to the Z-DEMATEL. The greater the consensus, the more experts' agreement. The results show an average difference of 3.2% in consensus among experts, which means a 96.8% confidence level. This also indicates that the 15 Z-DEMATEL questionnaires have a high degree of consensus.

Taking the Z-DEMATEL questionnaire of Expert 1 as an example, as in Table 3, Expert 1 considered the influence of C_1 on C_2 to be very great and was highly confident in the evaluation, so the linguistic variables were filled in as (VH, H). All other criteria were evaluated in the same way, and a matrix of direct influence relationships for the 15 linguistic variables was obtained for all expert evaluations. The Z-number-based matrix of direct influence relationships was obtained using the Z-number conversion rule, as in Table 4. Similarly, taking the direct influence of C_1 on C_2 as an example, (2.19, 3.06, 3.47) were the Z-numbers of C_1 on C_2.

After generating the initial group direct influence relationship matrix $\mathbf{A}$, through the normalization process, the elements in the normalized direct influence matrix number are scaled between 0 and 1, so that the units of the elements in the matrix can be unified without changing the original

data distribution, and the normalized direct influence matrix $\mathbf{X}$ is obtained. Next, considering the direct influence relationships and the indirect influence relationships, the normalized direct influence matrix $\mathbf{X}$ is accumulated and multiplied multiple times to obtain the total group influence relationship matrix $\mathbf{T}$, as shown in Table 5.

The final step is to sum the total influence matrix in the horizontal and vertical directions to produce $Z(\mathbf{r})$ and $Z(\mathbf{s})$. The total influence $(Z(\mathbf{r}) + Z(\mathbf{s}))$ and the net influence $(Z(\mathbf{r}) - Z(\mathbf{s}))$ can be obtained by adding and subtracting $Z(\mathbf{s})$ from $Z(\mathbf{r})$, respectively. Take C_1 as an example, its $Z(r_1) + Z(s_1)$ values are (0.99, 2.78, 10.74) and its $Z(r_1) - Z(s_1)$ values are (1.11, 3.01, 11.18), and $r_1 + s_1$ and $r_1 - s_1$ can be obtained by the defuzzification procedure. The total and net influences of all criteria can be obtained by following this procedure to C_{10}. Table 6 presents the results of the Z-DEMATEL analysis, in which the total influence $(r + s)$ is used to calculate the weight of the criteria, and the top five criteria with the highest weight values are C_1, C_8, C_5, C_3, and C_2, where C_8 and C_1 ranked first with a weight of 0.109.

The elements of the matrix $\mathbf{T}$ can be used to investigate the strengths of the criteria and their mutual influence. There $r + s$ is set as the horizontal axis and $r - s$ is set as the vertical axis. Each criterion is labeled with nodes according to its corresponding position, and then the numerical values of the elements of the matrix $\mathbf{T}$ are used to determine the influence strengths by drawing the influence arrows to create an INRM. The influence relationships of the criteria are shown in Figure 1. By visualizing the INRM, we can quickly understand which criteria are highly influential and consider them as the main causes, while on the other hand, criteria that are more significantly affected are considered as the effects. The criteria with stronger mutual influence are C_1, C_2, C_3, C_5, and C_8, and with the identification, it is beneficial to the subsequent formulation of management and improvement strategies.

5. Discussion

According to the Z-DEMATEL results, the top five most important criteria for electric bicycles are price (C_1) with a

TABLE 3: Direct relation matrix of expert 1 (linguistic variables).

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
C_1	—	(VH, H)	(VH, VH)	(VH, VH)	(VH, VH)	(M, VH)	(M, VH)	(H, VH)	(M, H)	(N, H)
C_2	(VH, H)	—	(VH, VH)	(VH, VH)	(VH, VH)	(M, VH)	(L, VH)	(H, VH)	(L, H)	(L, H)
C_3	(VH, H)	(VH, H)	—	(VH, VH)	(VH, VH)	(M, VH)	(N, VH)	(L, VH)	(N, H)	(N, H)
C_4	(VH, H)	(VH, H)	(VH, VH)	—	(H, VH)	(N, VH)	(L, VH)	(H, VH)	(N, H)	(N, H)
C_5	(VH, H)	(VH, H)	(VH, VH)	(VH, VH)	—	(L, VH)	(L, VH)	(M, VH)	(L, H)	(L, H)
C_6	(M, H)	(H, H)	(H, VH)	(H, VH)	(M, VH)	—	(N, VH)	(M, VH)	(N, H)	(N, H)
C_7	(M, H)	(L, H)	(L, VH)	(N, VH)	(M, VH)	(L, VH)	—	(M, VH)	(L, H)	(L, H)
C_8	(M, H)	(H, H)	(H, VH)	(VH, VH)	(M, VH)	(M, VH)	(L, VH)	—	(M, H)	(M, H)
C_9	(L, H)	(M, H)	(M, VH)	(M, VH)	(M, VH)	(M, VH)	(M, VH)	(M, VH)	—	(H, H)
C_{10}	(M, H)	(N, H)	(N, VH)	(N, VH)	(M, VH)	(N, VH)	(L, VH)	(M, VH)	(M, H)	—

TABLE 4: Direct relation matrix of the group (Z-numbers).

	C_1	C_2	C_3	C_4	...	C_{10}
C_1	(0.00, 0.00, 0.00)	(2.19, 3.06, 3.47)	(2.26, 3.15, 3.56)	(1.02, 1.73, 2.50)	...	(0.89, 1.51, 2.23)
C_2	(2.19, 3.05, 3.38)	(0.00, 0.00, 0.00)	(2.00, 2.90, 3.32)	(1.82, 2.60, 3.09)	...	(0.85, 1.59, 2.28)
C_3	(2.14, 3.03, 3.44)	(2.42, 3.33, 3.65)	(0.00, 0.00, 0.00)	(1.75, 2.56, 3.13)	...	(0.83, 1.53, 2.24)
C_4	(1.67, 2.50, 3.09)	(2.21, 3.13, 3.56)	(1.89, 2.83, 3.33)	(0.00, 0.00, 0.00)	...	(0.66, 1.31, 2.08)
...	...	...	...	...	...	...
C_{10}	(1.19, 1.87, 2.60)	(0.75, 1.26, 1.96)	(0.87, 1.51, 2.22)	(0.71, 1.36, 2.19)	...	(0.00, 0.00, 0.00)

TABLE 5: Group total influence matrix.

	C_1	C_2	C_3	C_4	...	C_{10}
C_1	(0.06, 0.24, 1.07)	(0.13, 0.32, 1.14)	(0.13, 0.33, 1.17)	(0.08, 0.25, 1.04)	...	(0.06, 0.20, 0.88)
C_2	(0.13, 0.32, 1.13)	(0.05, 0.21, 0.99)	(0.12, 0.31, 1.12)	(0.10, 0.26, 1.02)	...	(0.06, 0.19, 0.85)
C_3	(0.13, 0.33, 1.17)	(0.13, 0.32, 1.14)	(0.05, 0.22, 1.05)	(0.10, 0.27, 1.05)	...	(0.06, 0.20, 0.87)
C_4	(0.11, 0.30, 1.13)	(0.12, 0.30, 1.10)	(0.11, 0.30, 1.12)	(0.04, 0.18, 0.93)	...	(0.05, 0.18, 0.84)
...	...	...	...	...	...	...
C_{10}	(0.08, 0.24, 0.98)	(0.06, 0.21, 0.93)	(0.07, 0.22, 0.95)	(0.05, 0.19, 0.87)	...	(0.02, 0.11, 0.67)

TABLE 6: Z-DEMATEL results.

	$Z(\mathbf{r}) + Z(\mathbf{s})$	$Z(\mathbf{r}) - Z(\mathbf{s})$	$r + s$	$r - s$	Weight	Rank
C_1	(0.99, 2.78, 10.74)	(1.11, 3.01, 11.18)	8.901	−0.249	0.109	1
C_2	(0.88, 2.59, 10.29)	(1.01, 2.79, 10.78)	8.430	−0.250	0.103	5
C_3	(0.93, 2.70, 10.64)	(0.99, 2.84, 11.02)	8.664	−0.184	0.106	4
C_4	(0.84, 2.53, 10.33)	(0.78, 2.40, 10.05)	7.961	0.151	0.097	7
C_5	(1.00, 2.83, 10.92)	(0.95, 2.73, 10.76)	8.693	0.100	0.106	3
C_6	(0.89, 2.60, 10.48)	(0.87, 2.59, 10.57)	8.299	−0.011	0.102	6
C_7	(0.81, 2.46, 10.20)	(0.81, 2.43, 10.10)	7.922	0.035	0.097	8
C_8	(0.98, 2.79, 10.94)	(1.07, 2.96, 11.22)	8.931	−0.178	0.109	1
C_9	(0.79, 2.34, 9.71)	(0.63, 2.08, 9.12)	7.269	0.317	0.089	9
C_{10}	(0.69, 2.08, 8.97)	(0.57, 1.87, 8.43)	6.646	0.269	0.081	10

weighting of 0.109, safety (C_8) with a weighting of 0.109, power of engine (C_5) with a weighting of 0.106, battery durability (C_3) with a weighting of 0.106, and battery life (C_2) with a weighting of 0.103. This shows that the public's electric bicycle purchase considerations are mostly performance-oriented. The results are in line with Johnson and Rose's [43] study. The study mentioned that the motivation for purchasing an electric bicycle is to save labor 53.6%, replace a car 50.7%, maintain health and fitness 42.0%, climb mountains 40.6%, rehabilitate 34.8%, and environmental benefits 5.8%, all of which are needed for a better performance electric bicycle to meet the needs of consumers. In addition, optimizing the top five important criteria can effectively increase consumers' willingness to purchase electric bicycles. The top five criteria will be discussed separately. First, the criterion with the highest weight is the price of the vehicle (C_1), which echoes Kazemzadeh and Bansal's [44] study, in which the Swedish government began subsidizing electric bicycles in 2018 in order to achieve a sustainable transport subsidy. The government subsidizes 25% of the price of an electric bicycle for consumers in purchase. This shows that consumers are most sensitive to
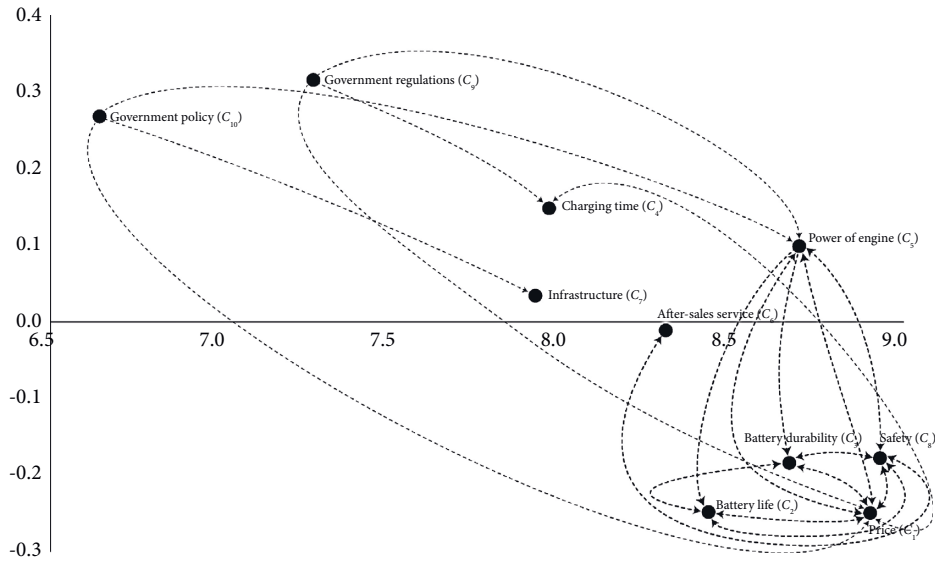
Figure 1: INRM of purchase intention factors of electric bicycles.

the price of the vehicle, and when the price of the vehicle is lowered or supported by government subsidies, consumers will be more willing to buy. At present, there are more than 500,000 electric bicycles in Taiwan. Apart from the elderly and children, the largest group of electric bicycle riders are foreign migrant workers. The price of electric bicycles in Taiwan is generally between NT\$20,000 and NT\$50,000, which is relatively cheap and easy to purchase compared with motorcycles, and does not require additional driving license and registration. For foreign migrant workers, electric bicycles are their first choice of transportation. If the price of electric bicycles can be lowered and there are government subsidies to purchase them, it will increase the popularity of electric bicycles in Taiwan and the willingness to purchase them.

The second most important criterion is safety (C_8), which is consistent with previous studies by Pejhan et al. [45]. Safety in driving and the operation of vehicles have always been one of the reasons why consumers value them. The study focused specifically on the vulnerability of riding electric bicycles on the road and the safety of user operation. Johnson and Rose [43] mention that the reason why electric bicycles are heavier than traditional bicycles is because of the difference in battery and component location planning. In addition, in accelerating, the speed will exceed the accidental speed, which will cause danger to the elderly and children. Therefore, in the planning and setting of electric bicycles, it is necessary to pay special attention to the user experience, in order to reduce user error and reduce the occurrence of man-made accidents. In Taiwan, since there are no specific regulations for electric bicycles, most users will modify them to pursue faster speeds. In terms of safety, the balance and speed of electric bicycles, modification restrictions, and regulations are needed to ensure the safety of road users. The third most important criterion is power of engine (C_5), which is the main power source of the electric bicycle and is used to assist the riding to save effort. Sałabun et al. [13]

suggest that a good motor has multiple modes to meet the needs of consumers in any situation, such as providing good riding assistance, proper motor positioning for overall bicycle stability, and good motor maintenance services. The fourth most important criterion is battery durability (C_3) and the fifth most important criterion is battery life (C_2). Oeser et al. [46] mention that batteries need to meet stringent criteria, such as long durability and a battery life of at least 10 years. Longer battery life can effectively reduce replacement and maintenance costs. Most of the batteries used in today's electric bicycles are mainly lithium batteries. Compared with nickel and lead batteries, lithium batteries produce more electricity, being lighter, and enjoying a longer service life. In addition, using the original charger, not overcharging the battery, and keeping the battery dry will ensure that the lithium battery is active and will last longer [47].

In addition, the plotted INRM shows that the power of engine (C_5) is found to be a key factor, with the main characteristics located in the upper right corner of the INRM, indicating that this factor has high degree of influence and high association and should be listed as a priority object. It affects price (C_1), safety (C_8), battery durability (C_3), and battery life (C_2). The relationships will be explained separately. The first is the effect of power of engine (C_5) on price (C_1). There are three main components that affect the price of an electric bicycle: motor, battery, and electronic control system, of which the motor is the most expensive. Its high cost also highlights its importance in electric bicycles. Obviously, the higher the manufacturing cost of the motor with better performance, the more likely to affect the price of the electric bicycle [35, 36]. Second, regarding the effect of power of engine (C_5) on safety (C_8), nowadays, in order to ensure safety, the maximum output power of engine is only 400 watts and the maximum riding speed is limited to 25 km/h, and the motor has a 3-second automatic power supply stop setting to provide safety to
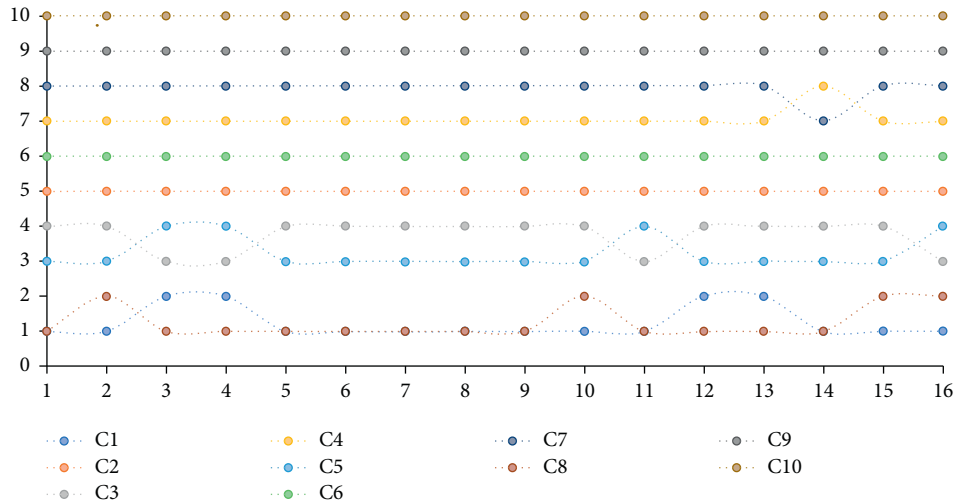
FIGURE 2: The 16 runs sensitivity analysis results.

users when the speed exceeds the speed limit, braking situation, short circuit, or malfunction of signal system [36, 48]. In terms of the effect of power of engine (C_5) on battery durability (C_3), the motor requires electricity to operate, and the speed can be effectively controlled by regulating the voltage level. Therefore, the longer the battery life, the more power the motor can use, which in turn will provide a constant flow of power [13]. Power of engine (C_5) has an influence on battery life (C_2), and the relationship between the motor and the battery is extremely close. The motor needs to operate efficiently for a long time, and the battery life must be long enough to effectively match the motor operation [13, 36].

Power of engine (C_5), safety (C_8), and after-sales service (C_6) have mutual influence on each other. Motor is the core element of electric bicycle and can be regarded as the heart of electric bicycle. When the motor is poorly designed or often damaged, it not only causes safety concerns, but also requires consumers to go to electric bicycle service stations for repairs, which increases the workload of the service stations and easily raises the cost of after-sales service, as well as risking consumer dissatisfaction with the after-sales service. Therefore, ensuring that the motor is not easily damaged can help reduce the impacts on after-sales service [13, 36]. Other mutual influence relationships can be examined one by one through INRM for their intended management implications.

Furthermore, government policy (C_{10}) and government regulations (C_9) can be found to have a moderate influence on the other factors. Government policy (C_{10}) and government regulations (C_9) in the upper left corner can be considered as secondary factors with high influence and low association, and are the second priority for improvement. Therefore, improving government policy (C_{10}) and government regulations (C_9) is also helpful in increasing consumer purchase intentions. It is primarily the role of government through a series of comprehensive plans and arrangements. Government commitment and public trust are often based on the integrity of regulations and institutions [49], so having clear policy support and regulations in place will help to ensure consumer safety on electric bicycles. Principles such as well-planned electric bicycle lanes, electric bicycle modification regulations, riding speed limits, and compliance with electric bicycle operators' vehicle safety inspection standards and related safety factors should be examined [50]. In addition, government policy and regulations can also protect consumers from purchasing electric bicycles at reasonable prices, avoid malicious price hikes by electric bicycle manufacturers, and establish a fair-trading environment for consumers [35]. When consumers purchase electric bicycles, the government provides friendly policies and regulations to subsidize consumers and operators, helping to increase the popularity and purchase rate of electric bicycles [17].

In order to check whether the individual subjective opinions of experts can affect the overall analysis results, a sensitivity analysis is therefore performed. After deleting the judgment of one expert, we perform Z-DEMATEL and record the ranking results of factors. A total of 16 replicates were performed (including the initial analysis, and the sequential exclusion of 15 experts). The ranking of factors is shown in Figure 2. It can be seen that the ranking change of each factor does not change significantly, despite a small change of 1 unit. In addition to ensuring expert representation through the Z-DEMATEL consensus test, sensitivity analysis can also be used to determine whether the personal judgments of these experts will significantly affect the results.

6. Conclusion

This article uses the MCDM concept to propose a purchase intention factors framework for electric bicycles. In order to effectively conduct an evaluation in an uncertain environment and measure the confidence of experts in evaluation, we introduce Z sets theory into the DEMATEL technique. Z-DEMATEL is used to identify the influential relationship among the factors and their influence weights. Our research

procedure is reproducible. Other products or industries can be analyzed following the analysis process.

The results of this study echo the results of many previous studies on electric bicycles. The DEMATEL-based approach neither require too many pre-determined assumptions to perform the calculation process, nor does it require a large sample size to conduct the survey as in statistical analysis, and the results obtained from interviewing only a few experienced experts in the field can provide good analytical information [51–53]. Overall, this study provides an appropriate electric bicycle purchase intention evaluation system to support consumers and practitioners in developing their strategies accurately. The importance of electric bicycles as environmentally friendly, relatively inexpensive, and suitable for all ethnic groups as a part of future urban transportation cannot be overlooked. This study provides an evaluation of the purchase intention of electric bicycles, which can help the industry to better understand the most important criteria for consumers to purchase electric bicycles and make adjustments to their management strategies:

(i) The electric bicycle purchase intention factors can be divided into two aspects: internal influence and external influence, with a total of ten criteria. The Z-DEMATEL method provides a clear ranking of the weight of the ten criteria. The top five important criteria are price (C_1), safety (C_8), power of engine (C_5), battery durability (C_3), and battery life (C_2), which show that consumers are most concerned about the performance of electric bicycles. Improvements to these five criteria will help increase consumer purchase intention.

(ii) Z-DEMATEL generates a visualized influential network relation map that can be used to identify the influence relationships among electric bicycle criteria. This shows that power of motor (C_5) is considered as the factor that most significantly affects other criteria, while safety (C_8) and price (C_1) are most likely to be affected by other criteria.

(iii) The current electric bicycle riding group in Taiwan is mainly foreign migrant workers, so if the price can be reduced and if the government subsidies are available, the sales volume of electric bicycles will increase.

Future research can consider criteria based on the perspective of sustainability to explore the development trend of electric bicycles, and incorporate economic, environmental, and social criteria into the evaluation. This will enable decision-makers to develop the electric vehicle market with a sense of sustainability. In the end, only 15 experts participated in this research, and we expect to interview more foreign scholars, practitioners, and electric bicycle experts in the future to increase the number of samples. In terms of methodology, there are other novel techniques for defining criterion interaction relationships, e.g., heterogeneous influence and strength attenuation (HISA) [54]. In the future, more data can be collected for analysis and comparison of multiple methods.

Nomenclature

Acronym:	Nomenclature
SDGs:	Sustainable development goals
CBD:	Convention on biological diversity
CONEBI:	Confederation of the European bicycle industry
U.S.:	United States
MCDM:	Multiple criteria decision-making
Z-DEMATEL:	Z-based decision-making trial and evaluation laboratory
INRM:	Influential network relation map
ISM:	Interpretative structural modeling
AHP:	Analytic hierarchy process
BWM:	Best-worst method
FUCOM:	Full consistency method
LBWA:	Level-based weight assessment.

Data Availability

All data generated or analyzed during the study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Ching-Te Lin contributed to preparing the original draft; Jen-Jen Yang contributed to the methodology; Wen-Jen Chiang contributed to the conceptualization; Jen-Jung Yang contributed to the investigation and data curation; Chin-Cheng Yang performed the review and editing work.

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