A STUDY ON EVALUATING CRITERIA FOR ELECTRIC BICYCLE PURCHASE USING ISM AND ANP METHODS

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ABSTRACT

This study explores the increasingly complex nature of product design in customer-oriented industries due to the diversification and complexity of customer demands. The multiplicity of customer expectations complicates product design decisions. The aim of this study is to deeply understand the attributes of customer demand when purchasing electric bicycles, and to integrate Interpretive Structural Modelling (ISM) and Analytic Network Process (ANP) to assess the impact and interrelationships of these attributes. ISM is used to calculate the relationships between attributes, while ANP ensures the consistency and accuracy of evaluation weights to identify the priority improvement sequence most valued by customers. The study identifies five major evaluation criteria for electric bicycles: functionality, price and brand perception, practicality and performance, aesthetics, and safety. Among these criteria, safety emerges as the most prominent concern for customers, focusing primarily on the reliability of braking systems, anti-skid tires, and nighttime riding lights. Following safety, practicality and performance considerations include factors such as range, charging time, vehicle weight, maximum speed, and climbing capability. Functionality ranks third in customer preferences, highlighting the importance of diverse features such as electric assist modes, multi-speed transmissions, and suspension systems. In terms of price and brand perception, consumers not only consider price competitiveness and brand reputation but also place significant emphasis on the completeness of after-sales service and warranty terms. Lastly, while aesthetics holds a relatively lower weight in overall criteria, consumer interest in exterior design and color coordination directly impacts product marketability and consumer purchasing decisions. In conclusion, these research findings provide crucial market insights to manufacturers, guiding product design directions and adjustments in market strategies to enhance product competitiveness and overall customer satisfaction.

KEYWORDS

Analytic Network Process, Interpretive Structural Modelling, electric bicycle purchase

1. INTRODUCTION

In today's customer-oriented industry, as customer awareness and demands evolve, product design trends towards diversification and variety. Meeting these customer demands has made product design decisions increasingly complex and challenging [1-3]. Decision-makers must carefully consider and evaluate various attributes to determine customer needs and establish evaluative criteria for systematic decision analysis. Customers consider attributes such as functionality, comfort, aesthetics, and price when purchasing products. In the highly competitive product design process, designers must clearly understand these attributes and their significance to aid in product design, development, and decision-making [4-6].

DOI: 10.5121/ijcsit.2024.16406

Customers prioritize attributes differently when making purchasing decisions, often sacrificing one attribute for another that satisfies their needs. These attributes interact and influence each other, making it crucial to analyze their interrelationships. Therefore, this study integrates Interpretive Structural Modeling (ISM) and Analytic Network Process (ANP) to calculate the weights of each factor. This approach helps designers or decision-makers better understand customer purchasing behaviors, ensuring products align more closely with market demands.

This research combines ISM and ANP to evaluate the impact of each attribute, aiming to establish comprehensive evaluation criteria for customer product selection. It provides objective and quantitative analysis as a reference basis. Establishing this model ensures electric bicycle products are designed to better meet customer and market needs. The integrated information serves as criteria for designers, aiding in design planning and providing substantial benefits during initial design and validation stages. Further enhancements can refine this model into a decision-making mechanism for comparing and selecting options, thereby improving the accuracy and value of product decision outcomes.

2. Literature Review

2.1. Interpretive Structural Modelling (ISM)

Interpretive Structural Modelling(ISM) is a structured modelling method in social systems engineering proposed by Warfield in 1976 [7]. ISM uses graph theory and hierarchical directed graphs to describe the logical relationships among targeted elements, transforming abstract element sequences into concrete and comprehensive hierarchical structure graphs. This model effectively clarifies the interrelationships among elements, organizing complexity into structured order. ISM constructs models through systematic steps, including identifying relevant elements, establishing mutual relationship matrices, generating directed graphs, and hierarchical structure diagrams [7, 8]. ISM finds various applications in policy-making, management decisions, technical planning, and system design. Its advantage lies in providing clear visual models that aid decision-makers in understanding and analyzing complex relationships [8]. In practical applications, ISM helps identify and analyze key factors, revealing their interdependencies and influences. It is often used in conjunction with other analytical methods to enhance accuracy and reliability [9].

2.2. Analytic Network Process (ANP)

Analytic Network Process (ANP), proposed by American operations research expert Thomas L. Saaty in 1996 [10], is a multicriteria decision-making method designed to address complexity and interdependencies among elements in decision-making processes. Unlike traditional Analytic Hierarchy Process (AHP), ANP considers not only the hierarchical structure of decision elements but also their interdependencies and feedback effects, making it more suitable for complex decision scenarios in the real world [10, 11]. The basic concepts and steps of ANP include:

(1) **Constructing Decision Network Models**: Establishing the overall framework of the decision problem, including identifying decision goals, criteria, sub-criteria, and alternative solutions, and creating corresponding network structure diagrams.

(2) **Constructing Comparison Matrices**: Using pairwise comparisons to determine the relative importance between each element, filling in the comparison matrices.

(3) **Calculating Supermatrix**: Compiling weight values from the comparison matrices to form a supermatrix that reflects the mutual influence relationships among all decision elements.

(4) **Deriving Weight Vectors**: Normalizing the supermatrix and iteratively calculating stable weight vectors.

(5) **Integrated Weight Assessment**: Using the weight vector to comprehensively evaluate alternative solutions, thereby determining the optimal solution.

ANP is widely applied in business management, policy-making, technology selection, risk assessment, and resource allocation. Its primary advantage lies in comprehensively considering the interdependencies among decision elements, effectively handling decision problems in complex systems. Adopting ANP enhances the scientific rigor of decision processes and the rationality of decision outcomes, playing a crucial role in modern multi-criteria decision analysis.

2.3. Evaluation Criteria For Purchasing Electric Bicycles

The development of electric bicycles in Taiwan demonstrates several key characteristics and trends [12-14]:

(1) **Increasing Market Demand**: With growing demand for environmentally friendly transportation options, Taiwan's electric bicycle market is expanding. Especially with increased demand for urban commuting and short-distance travel, electric bicycles have become a popular choice.

(2) **Technological Innovation and Product Diversity**: Taiwan's electric bicycle industry continues to progress in technological innovation and product design. Manufacturers continuously introduce new electric assistance systems, lighter battery technologies, smart control systems, and diversified models and feature designs to meet various consumer needs.

(3) **Policy Support and Regulatory Environment**: The Taiwanese government actively supports the use of green transportation vehicles through various subsidies and adjustments to regulatory environments to promote the adoption and use of electric bicycles. These policies include subsidies, tax incentives, and related infrastructure construction.

(4) **Quality and Safety**: Electric bicycles manufactured in Taiwan typically emphasize quality and safety, complying with international standards and certification requirements. These products perform well in terms of performance, durability, and user safety, enhancing consumer trust and market competitiveness.

(5) **Export Markets and Global Influence**: Taiwan's electric bicycles not only sell well in the local market but also export a considerable portion worldwide, especially in European and North American markets. Taiwanese-manufactured electric bicycles are gradually expanding their influence in the global market due to their high quality, innovation, and competitiveness.

When purchasing electric bicycles, consider the detailed explanations of the following seven main considerations [15-17]:

(1) **Performance and Functionality**:

[1] Range and battery capacity
[2] Charging time
[3] Electric assistance modes and multiple gear shifts

[4] Suspension system and braking performance

(2) **Design and Convenience**:

[1] Weight and portability
[2] Night riding lights and anti-theft systems

(3) **Safety**:

[1] Brake system sensitivity and reliability
[2] Anti-slip tires and riding safety

(4) **Quality and Durability**:

[1] Battery life and replacement costs
[2] After-sales service and warranty period

(5) **Brand Reputation**: Brand reputation and word of mouth.

(6) **Aesthetics and Personalization**: Body color and design style.

(7) **Cost-effectiveness**: Product price and value for money.

3. Research Methodology

In formulating the evaluation criteria to assess consumer preferences for products, this study relies on insights gleaned from extensive literature reviews. Market research and analysis were conducted on existing products to collect data pertinent to consumer evaluations and related issues [18-21]. Furthermore, customer demand indicators and perceptions were gathered through interviews with sales personnel, analysis of customer complaints, and information provided by the marketing department. Criteria identified from the literature review and stakeholder interviews were consolidated. The modified Delphi method [22-28] involving 11 experts and industry stakeholders was utilized to validate the criteria and sub-criteria for evaluating electric bicycle purchasing decisions (refer to Table 1), followed by a survey to gauge their significance.

Table 1. Criteria and Sub-criteria for Evaluating Electric Bicycle Purchases

Criteria	Description	Sub-criteria
Functionality (A)	Besides basic riding functions, additional features of electric bicycles that are crucial considerations for consumers, directly impacting user experience and convenience.	Electric assistance mode (A1)
		Multiple gears (A2)
		Suspension system (A3)
		Smart display screen (A4)
		USB charging port (A5)
Price and Brand (B)	Product price and brand image, influencing primary factors in purchase decisions, especially brand reputation and after-sales service which significantly affect consumer confidence.	Product price (B1)
		After-sales service and warranty period (B2)
		Brand reputation (B3)
Practicality and Performance (C)	Practicality and performance are core indicators for electric bicycles, directly affecting their daily usability and durability.	Range (C1)
		Charging time (C2)
		Bike weight (C3)
		Maximum speed (C4)
		Climbing capability (C5)
Aesthetics (D)	Product appearance and design.	Bike color (D1)
		Design aesthetics (D2)
		Bike material (D3)
Safety (E)	Safety during usage is a critical indicator for any transportation vehicle, directly related to user life and property safety.	Brake system reliability (E1)
		Anti-slip tires (E2)
		Night riding lights (E3)
		Anti-theft system (E4)

4. EMPIRICAL RESULTS

In real-world purchasing situations, customers prioritize criteria according to their satisfaction with specific attributes, sometimes at the expense of others. These criteria are interrelated, mutually influencing one another. Hence, this research integrates the ISM and ANP methodologies to analyze and assign weights to these factors. This integrated approach enables designers and decision-makers to gain deeper insights into customer purchasing behaviors, thereby enhancing the alignment of products with market demands. The computational process that combines ISM and ANP is detailed in [7-11].

Phase 1: Interpretive Structural Modelling (ISM)

This study synthesized primary criteria and sub-criteria from relevant literature [18-21]. Eleven experienced industry experts were interviewed to confirm five major criteria: functionality, price and brand, practicality and performance, aesthetics, and safety. Twenty sub-criteria were identified under these five main criteria. Expert opinions were consolidated to construct the hierarchical framework of this study. To align with the nature of decision problems, the second stage involved expert surveys to execute the analysis of the ISM, establishing interdependencies and feedback among criteria.

Phase 2: Analytic Network Process (ANP) [10, 11]

Step 1: Developing Hierarchical and Interdependent Models

- Create the Structural Self-Interaction Matrix (SSIM).
- Derive the Initial Reachability Matrix from the SSIM, accounting for transitive relationships between criteria, resulting in the Final Reachability Matrix (RM). This matrix illustrates reciprocal dependencies and feedback interactions among criteria.

Step 2: Formulating Pairwise Comparison Matrices and Calculating Eigenvalues and Eigenvectors Decision-makers input subjective assessments into pairwise comparison matrices based on their judgments. Achieving consistency across decision-makers in complex hierarchical structures and factors can be challenging. Saaty [10, 11] recommends using the Consistency Index (C.I.) and Consistency Ratio (C.R.) to evaluate the reliability and consistency of comparison matrices.

This structured integration of ISM and ANP enhances the comprehension of criteria interrelationships and their effects, facilitating informed decision-making in product design and marketing strategies.

- Consistency Index (C.I.): The formula is $C.I. = \frac{\lambda_{max}-n}{n-1} C.I. = \frac{\lambda_{max}-n}{n-1}$, where λ_{max}represents the maximum eigenvalue and n denotes the order of the matrix. A C.I. value of 0 indicates perfect consistency, while C.I. > 0.10 suggests inconsistency. Saaty recommends maintaining C.I. ≤ 0.10 as an acceptable level of consistency.

- Consistency Ratio (C.R.): The equation is $C.R. = \frac{C.I.}{R.I.}$, where R.I. stands for the Random Index that varies with the matrix order. According to Saaty's guidance, if C.R. ≤ 0.1, the pairwise comparison values within the matrix demonstrate acceptable consistency.

This study assessed the pairwise comparison matrices for criteria (refer to Table 2) and matrices comparing relative weights among sub-criteria (refer to Tables 3 to 7).

Step 3: Construction of Supermatrix and Calculation of Aspect and Criterion Weight Table

The ANP method involves a calculation process that includes three matrices: the unweighted supermatrix, weighted supermatrix, and limit supermatrix. By integrating the limit supermatrix operation, the resulting weights correspond to each criterion based on the convergence values derived from this matrix. Table 8 presents the aspect and criterion weight table used in this study.

Table 2. Pairwise Comparison Matrix for Evaluating Criteria

Criteria*	A	B	C	D	E	Description
A	1	1.4433	0.3667	2.8833	0.2055	λ_{max}=5.2012
B	0.6928	1	0.3167	2.0333	0.4292	C.I.= 0.0503
C	2.7274	3.1581	1	3.2200	0.5519	C.R.= 0.0449
D	0.3468	0.4918	0.3106	1	0.2380	n=5
E	4.8658	2.3301	1.8121	4.2026	1	R.I.=1.12

*. For an explanation of the codes, please refer to Table 1.

Table 3. Pairwise Comparison Matrix for Functional (A) Criteria

Sub-criteria*	A1	A2	A3	A4	A5	Description
A1	1	2.5833	1.9167	1.0556	2.6667	λ_{max}=5.3725 C.I.= 0.0931 C.R.= 0.0831 n=5 R.I.=1.12
A2	0.3871	1	0.4333	0.8349	2.2238	
A3	0.5217	2.3078	1	1.9667	1.0250	
A4	0.9474	1.1977	0.5085	1	3.1039	
A5	0.3750	0.4497	0.9756	0.3222	1	
*. For an explanation of the codes, please refer to Table 1.						

Table 4. Pairwise Comparison Matrix for Price and Brand (B) Criteria

Sub-criteria*	B1	B2	B3	Description
B1	1	0.5969	0.8821	λ_{max}=3.0048 C.I.=0.0024 C.R.=0.0042 n=3 R.I.=0.58
B2	1.6669	1	1.1933	
B3	1.1337	0.8380	1	
*. For an explanation of the codes, please refer to Table 1.				

Table 5. Pairwise Comparison Matrix for Practicality and Performance (C) Criteria

Sub-criteria*	C1	C2	C3	C4	C5	Description
C1	1	2.2667	3.8667	2.0040	1.3185	λ_{max}=5.3977 C.I.= 0.0949 C.R.= 0.0892 n=5 R.I.=1.12
C2	0.4412	1	1.4583	2.3070	0.4139	
C3	0.2586	0.6857	1	0.7372	0.3324	
C4	0.5080	0.4348	1.3565	1	1.6389	
C5	0.7584	2.4161	3.0086	0.6102	1	
*. For an explanation of the codes, please refer to Table 1.						

Table 6. Pairwise Comparison Matrix for Aesthetics (D) Criteria

Sub-criteria*	D1	D2	D3	Description
D1	1	0.8519	1.7850	λ_{max}=3.0052 C.I.=0.0026 C.R.=0.0045 n=3 R.I.=0.58
D2	1.1739	1	2.6010	
D3	0.5602	0.3846	1	
*. For an explanation of the codes, please refer to Table 1.				

Table 7. Pairwise Comparison Matrix for Safety (E) Criteria

Sub-criteria*	E1	E2	E3	E4	Description
E1	1	1.6306	1.2817	2.5017	λ_{max}=4.0303 C.I.=0.0101 C.R.=0.0112 n=4 R.I.=0.9
E2	0.6133	1	1.1167	1.5010	
E3	0.7802	0.8955	1	2.3685	
E4	0.3997	0.6667	0.4222	1	

*. For an explanation of the codes, please refer to Table 1.

Table 8. Weight Table of Evaluation Criteria and Sub-criteria

Criteria*	Local Weights[1]	Ranking	Sub-criteria*	Local Weights	Global Weights[2]	Ranking
A	0.1345	3	A1	0.3037	0.0408	10
			A2	0.1450	0.0195	18
			A3	0.2313	0.0311	14
			A4	0.2120	0.0285	15
			A5	0.1080	0.0145	19
B	0.1206	4	B1	0.2653	0.0320	12
			B2	0.4123	0.0497	7
			B3	0.3224	0.0389	11
C	0.278	2	C1	0.3228	0.0897	4
			C2	0.1733	0.0482	8
			C3	0.0927	0.0258	16
			C4	0.1717	0.0477	9
			C5	0.2395	0.0666	5
D	0.0698	5	D1	0.3594	0.0251	17
			D2	0.4531	0.0316	13
			D3	0.1875	0.0131	20
E	0.3971	1	E1	0.3555	0.1412	1
			E2	0.2385	0.0947	3
			E3	0.2690	0.1068	2
			E4	0.1371	0.0544	6

*. For an explanation of the codes, please refer to Table 1.
[1]. Local weight is determined based on judgments of a single criterion.
[2]. Global weight is determined by multiplying the weight of the criteria.

4.2. Evaluation Criteria and Sub-Criteria Weight Calculation Results

When consumers choose electric bicycles, their top five main criteria are: Safety (E), Practicality and Performance (C), Functionality (A), Price and Brand Perception (B), and Aesthetics (D). These main criteria reflect consumers' primary concerns and preferences in their purchasing decisions. Under these main criteria, specific sub-criteria also play crucial roles, further delineating consumer preferences and needs.

(1) **Safety (Criterion E)** holds the highest weight in the overall criteria, at 39.71%. Consumers prioritize safety features such as brake system reliability, anti-slip tires, and night riding lights, which directly influence their confidence and choice in riding safety. Within the sub-criteria, E1 (Brake System Reliability) has the highest weight at 35.55%, highlighting consumers' high concern for brake system reliability.

(2) **Practicality and Performance (Criterion C)** ranks second in the overall criteria, with a weight of 27.8%. Consumers particularly value factors like battery range, charging time, vehicle weight, maximum speed, and climbing ability, which directly impact the practicality and daily usability of the product. Among the sub-criteria, C1 (Battery Range) and C5 (Climbing Ability) hold weights of 32.28% and 23.95%, respectively, underscoring consumers' high priority on extending battery range and effective climbing performance.

(3) **Functionality (Criterion A)** holds a weight of 13.45% in the overall criteria, ranking third. Diverse functionalities such as electric assist modes, multi-gear transmissions, suspension systems, smart displays, and USB charging ports significantly influence user experience and convenience. Among the sub-criteria, A1 (Electric Assist Modes) has the highest weight at 30.37%, highlighting the importance of diverse assist modes for user convenience and riding experience.

(4) **Price and Brand Perception (Criterion B)** holds a weight of 12.06% in the overall criteria, ranking fourth. When choosing electric bicycles, consumers consider the competitiveness of product pricing and the reputation of the brand's after-sales service, which directly affect their purchase decisions. Notably, sub-criterion B2 (After-sales Service and Warranty Period) leads with the highest weight of 41.23%, emphasizing consumers' emphasis on robust after-sales support and warranty terms in brand selection.

(5) **Aesthetics (Criterion D)** holds a weight of 6.98% in the overall criteria, ranking fifth. While aesthetics are relatively secondary in consumer choice, factors such as exterior design, color coordination, and overall aesthetic appeal still significantly impact product market competitiveness and consumer satisfaction. However, D2 (Design Aesthetics) has the highest weight at 45.31%, indicating consumers' high concern for design aesthetics, which plays a crucial role in purchase decisions.

The detailed analysis of these sub-criteria highlights consumers' specific considerations and preferences when choosing electric bicycles. Manufacturers and marketers can use these insights to optimize product design and market positioning strategies, thereby meeting consumer needs and enhancing product competitiveness.

5. Conclusion and Recommendations

Based on the research findings, consumers demonstrate a diverse and varied demand for product attributes when selecting electric bicycles. This study utilized Interpretive Structural Modelling (ISM) and Analytic Network Process (ANP) to assess the impact of five major criteria: Safety, Utility and Performance, Functionality, Price and Brand Perception, and Aesthetics. The conclusions and recommendations are as follows:

Firstly, Safety holds the highest weight in consumer choices, indicating a high priority on safety features such as reliable braking systems, anti-slip tires, and night-time riding lights. These safety features directly influence consumers' sense of riding security and their purchase decisions, thus manufacturers should prioritize continuous improvement and optimization of safety technologies. Secondly, Utility and Performance are of significant concern to consumers, particularly factors like range per charge, charging time, vehicle weight, maximum speed, and climbing ability. These performance indicators directly impact product utility and daily usability, suggesting that enhancements and optimizations in these areas should be emphasized during product design.

Functionality ranks third in consumer preferences, highlighting the importance of diverse features such as electric assist modes, multi-gear transmission, and suspension systems for convenience. This underscores the need for manufacturers to continue diversifying product functionalities to meet varied consumer needs. Regarding Price and Brand Perception, consumers consider price competitiveness and brand reputation, with a strong emphasis on comprehensive after-sales service and warranty terms. This underscores the importance of brand trust and post-purchase support in consumer purchasing decisions, prompting manufacturers to strengthen brand value and enhance their after-sales service systems.

Lastly, Aesthetics, while carrying a lower overall weight, remains significant as consumers do not overlook design aesthetics such as exterior design, color coordination, and overall visual appeal. Enhancing product aesthetics can significantly impact market competitiveness and consumer satisfaction.

In conclusion, this study provides deep insights into consumer needs and preferences, offering essential strategic guidance for manufacturers in product design, feature configuration, and market positioning. Continuous improvement and optimization based on these key criteria can better align products with consumer expectations, thereby enhancing market competitiveness and overall consumer satisfaction.

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