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Functional Optimization of Smart Street Lamp via Hybrid Kano-DEMATEL Model: A Case Study on Hebi Area, China

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Abstract

World's major cities are rapidly advancing towards the development of smart cities. Smart street lamps, due to their integration and systematization, have become among the most promising physical infrastructure for realizing smart city construction. However, current smart street lamps face challenges. The function setting of smart street lamps is a prominent challenge. Research how to optimize function settings to enhance cost-effectiveness and practicality is crucial. However, existing research in this area is limited. This paper proposes a novel approach that leverages the strengths of the Kano model and the DEMATEL method, culminating in the establishment of a hybrid Kano-DEMATEL Model for comprehensively ranking smart street lamp functions. The model comprises four layers: the target layer, the Kano criterion layer, the DEMATEL criterion layer, and the requirements sorting table layer. The ordering strategy involves using the Kano model as the primary criterion and complementing it with the DEMATEL method as the secondary criterion. The model operates with specific rules as follows: The target layer serves as the product requirements iteration strategy. The Kano criteria layer is used to initially prioritize product requirements, following the order of M > O > A > I, and retaining only essential, expected, and attractive attributes. The DEMATEL criteria layer identifies key requirements and their interrelationships using the Centrality-Causality Map method. Further prioritization is conducted based on the DEMATEL quadrant order: Quadrant I > Quadrant II > Quadrant III > Quadrant IV. Within the same DEMATEL quadrant, requirements are ranked by centrality from high to low. After qualitative and quantitative dual sorting of all requirements, a requirement prioritization table is established. This model brings clarity to the importance of optimizing various indicators, provides a clearer understanding of the strengths and weaknesses of product functions, and considers correlations and complementarities between different functions, ultimately enhancing the cost-effectiveness and practicality of smart street lamps. By applying this model, this paper obtained a thorough ranking of the 21 must-be, expected, and attractive functions of smart street lamps. Furthermore, aligning these findings with specific regional research requirement, the functions of new smart street lamps were successfully optimized in the Hebi area, leading to substantial improvements and successful construction outcomes.

1. Introduction

As major cities continue to develop and expand globally, challenges such as population growth and traffic congestion arise, making smart cities an effective solution to address these issues while enhancing urban competitiveness. Consequently, smart street lamps have emerged as the optimal physical infrastructure for realizing smart city construction, with their orderly arrangement, efficient communication positioning, and stable power supply [1]. These smart street lamps not only provide basic illumination but also integrate various sensing devices and communication technologies to gather a wealth of urban data, supporting city management and intelligent services. Examples of these intelligent services include energy conservation, emissions reduction, and smart traffic navigation [2].

However, current smart street lamps face obstacles such as redundant functions, haphazard design, and lack of consideration for urban residents' emotional needs, impeding their healthy development. Notably, the challenge of function setting in smart street lamps, such as the rationality and compatibility of certain functions, and potential redundancy, results in high prices, costly implementation, and difficulties in maintenance and upgrades[3–7]. Therefore, optimizing the function setting of smart street lamps and enhancing their cost-effectiveness and practicality points to crucial research directions.

Various scholars have explored the optimization of multi-functional products, including smart street lamps. For instance, Pattanshetti and Attar proposed an optimal feature selection method based on mathematical models and optimization algorithms for multi-functional decision-making problems [8]. Li et al. introduced a genetic algorithm-based multi-objective optimization method, searching for the best feature combinations while considering multiple objectives [9]. Similarly, researchers have suggested that smart street lamps should possess basic illumination, intelligent traffic, environmental monitoring, public safety, and public information dissemination functions [10]. Yan adopted modular thinking to group smart street lamp functions based on actual needs, reducing application costs [11].

However, existing research remains limited due to a lack of systematic and quantitative analysis methods and inadequate exploration of the complexity and interrelationships between functional integration. As a result, it fails to sufficiently address redundant and mismatched function settings in smart street lamps.

To address the redundancy and mismatch of function settings in smart street lamps, this paper proposes the adoption of the hybrid Kano-DEMATEL model. The Kano model is a user needs analysis model that classifies and ranks product functions, offering insights into consumer demands for product performance and guiding design and development [12]. On the other hand, the DEMATEL method is a structural equation model that optimizes the relationships among multiple indicators, providing a comprehensive ranking and measuring the relationships and influences between different factors [13]. By integrating the Kano model and the DEMATEL method, the significance of optimizing various indicators becomes clear. This leads to a better understanding of the strengths and weaknesses of product functions, considering correlations and complementarities between functions. Ultimately, this integration enhances the cost-effectiveness and practicality of smart street lamps, with the final outcome aiming to optimize their performance.

The remainder of the paper is structured as follows: Section 2 outlines the hybrid Kano-DEMATEL model and the research methodology. Section 3 presents the findings from the Kano research. Section 4 discusses the results of the DEMATEL survey and data analysis. Section 5 discuss the finding. Finally, section 6 concludes the research findings.

2. Methodology

This section elaborates in general what type of survey and tools have been used by present researchers based on Kano model and DEMATEL method.

2.1 Kano Model

The Kano model divides the determined quality characteristics into 5 categories by the physical compliance of a certain quality characteristic described by the horizontal axis and the customer satisfaction described by its vertical axis [14]. This is shown in Figure 1. In Figure 1, the Kano model illustrates the classification of five types of requirements as follows:

i. **Attractive:** High improvement in a particular function/service leads to a noticeable increase in user satisfaction. If the function/service is absent, user satisfaction decreases minimally.
ii. **One-dimensional:** High improvement in a certain function/service results in an increase in user satisfaction. If the function/service is absent, user satisfaction will decrease.
iii. **Must-be:** High improvement in a specific function/service does not significantly increase user satisfaction. However, if the function/service is absent, user satisfaction will significantly decrease.
iv. **Indifferent:** There is no significant relationship between a particular function/service and user satisfaction.

v. **Reverse:** High improvement in a certain function/service actually leads to a decrease in user satisfaction.

The classification of functional elements in the Kano model is determined through questionnaire surveys, considering both positive and negative aspects, to assess customers' preferences. The specific classification criteria are presented in Table 1, where each letter corresponds to one of the five quality elements in the Kano model.

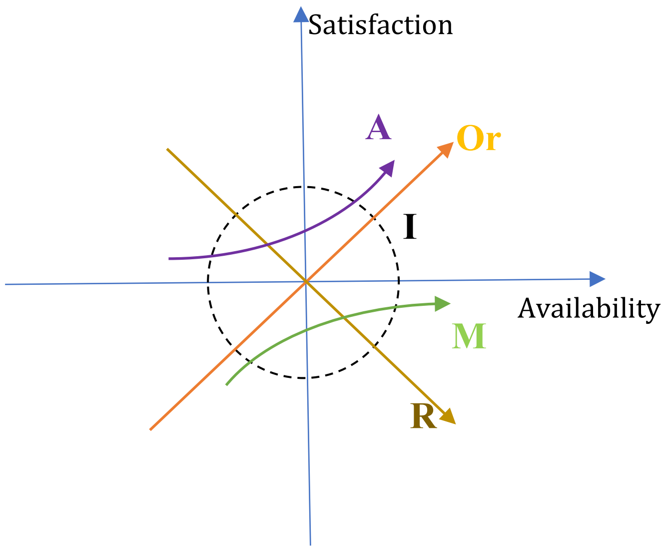

Fig. 1 *Schematic diagram of Kano model*

Table 1 *Classification and comparison table of Kano model evaluation results*

Features/Services		Negative questions: Dislike (1 point).	Tolerable (2 points).	It doesn't matter (3 points).	As it should be (4 points).	Like (5 points).
Positive questions	Dislike (1 point).	Q	R	R	R	R
	Tolerable (2 points).	M	I	I	I	R
	It doesn't matter (3 points).	M	I	I	I	R
	As it should be (4 points).	M	I	I	I	R
	Like (5 points).	Or	A	A	A	Q

A: Attractive, O: One-dimensional, M: Must-be, I: Indifferent, R: Reverse, Q: Suspect attribute

In order to obtain the priority ranking of requirements more intuitively, Berger et al. proposed the Better-Worse satisfaction coefficient calculation formula, which can calculate the satisfaction coefficient and dissatisfaction coefficient of each demand. When calculating, the undifferentiated demand and the reverse demand are removed [15]. The specific calculation equations are as Equation (1) and Equation (2). The product provides this demand, and the Better coefficient is:

$$\text{Better} = \frac{A' + O'}{A' + O' + M' + I'} \tag{1}$$

Formula:
A'-Number of charm demand options;
O'-Number of desired demand options;
M'-Number of required demand options;
I'-Number of undifferentiated demand options.

The product does not provide this requirement, and the Worse coefficient is:

$$Worse = \frac{O^{'} + M^{'}}{A^{'} + O^{'} + M^{'} + I^{'}} \tag{2}$$

According to the values of Better and Worse coefficients, the demand quartile plot is plotted, and the ordering principle is M> O> A> I [16]. In this study, a comprehensive collection of smart street lamp functions will be undertaken. Subsequently, these functions will be organized into a five-level Kano survey questionnaire, considering both positive and negative aspects. The attribute classification method of the Kano model, as depicted in Figure 2, will be utilized, along with the application of the Better-Worse satisfaction coefficient, to conduct the initial function attribute classification.

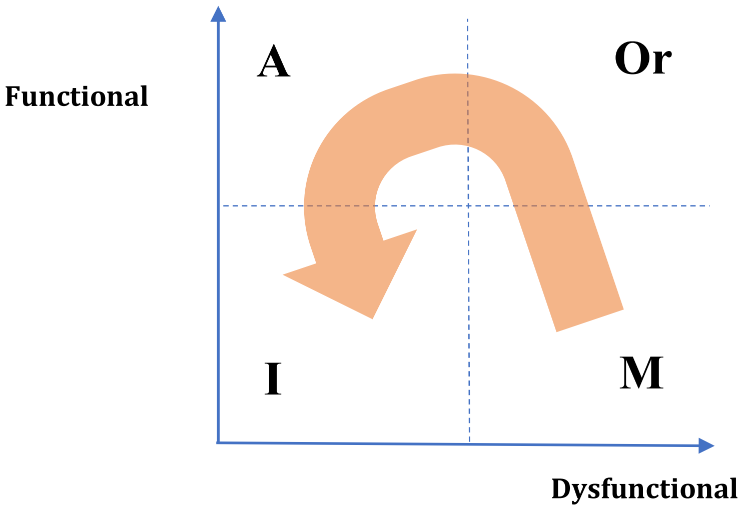

Fig. 2 *Implementation order of various requirements in the Kano model*

2.2 DEMATEL Method

The DEMATEL (Decision Making Trial and Evaluation Laboratory) method is applicable for studying the interrelationships among objective factors. Its essence lies in employing graph theory and matrix tools to determine the logical structural relationships between factors and identifying key factors within a system. This enables the resolution of complex problems [17]. The Centrality-Causality diagram is the primary tool in DEMATEL methodology for analyzing issues. It aids in establishing cause-and-effect relationships between requirements and ascertaining the significance of each requirement within the system. This, in turn, helps decision-makers to comprehend and explore intricate problem clusters and identify feasible solutions [18]. Currently, the DEMATEL method finds broad application in areas such as analyzing data quality in e-commerce, identifying information in complex networks, and discerning critical influencing factors within systems [19].

In combination with the DEMATEL analysis method, incorporating expert opinions allows for further exploration of the interrelations between requirements and transforms them into a more objective approach for prioritizing product requirements. The concise calculation steps are as follows:

1. Assigning pairwise impact scores to the requirements, quantifying the cause-and-effect relationships between them, to obtain the direct impact matrix A, where aij denotes the extent to which requirement i affects requirement j.
2. By using equations (3) and (4), the normalized direct impact matrix N can be obtained:

$$N = \frac{A}{s} \tag{3}$$

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$$s = \max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij} \tag{4}$$

3. Solve the comprehensive impact matrix T.

$$T = N(1-N)^{-1} \tag{5}$$

Formula: I-Identity matrix

4. Set the threshold and centrality-causality relationship diagram coordinate information. The centrality-causality relationship diagram is constructed based on the comprehensive influence matrix T information, and the coordinate information is shown in Table 2.
5. The centrality-causality relationship diagram is divided into four quadrants to determine the demand category. By calculating the average of the horizontal vector centrality D+R and the vertical vector causeway degree D-R, the centrality-causality relationship is plotted into four quadrants, as shown in Figure 3. In the four-quadrant impact causality diagram, each quadrant represents a different meaning and characteristics, and the location of the specific requirement in the diagram can be used to determine the category of the requirement to which it belongs [20].

Table 2 *The coordinate Information definitions of the centrality-causality relationship diagram*

Coordinate information	Definition
Impact degree D value	The comprehensive impact value of one element on other features, the larger the value means the greater the impact.
Affected degree C value	The comprehensive influence value of a certain element by other elements, the larger the value means the greater the degree of influence.
The centrality D+C value	The size of a feature's role in the system, a larger value means that the feature is more important;
Causeway degree D-C value	The impact of a feature on other features, a value greater than 0 means more influence on other. features, that is, the cause factor, and a value less than 0 means more influence by other features, that is, a result factor.

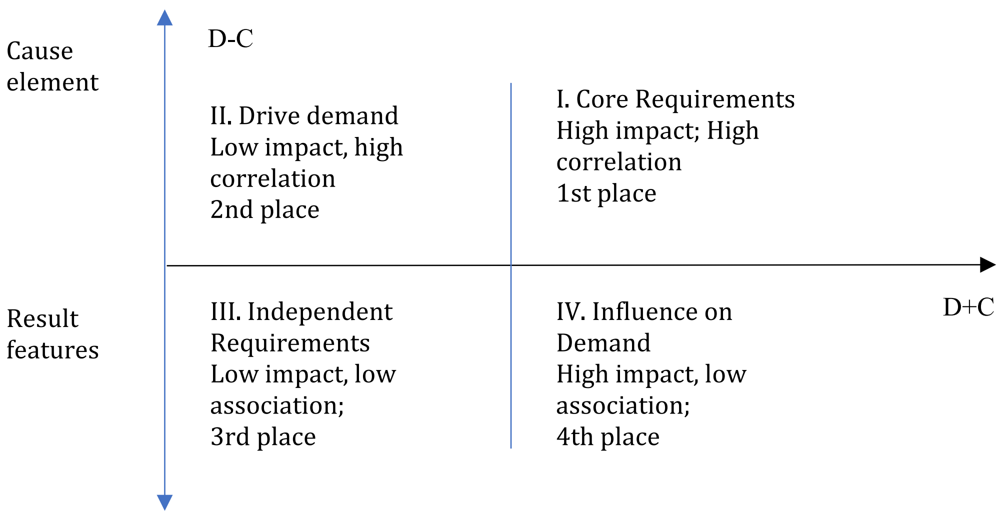

Fig. 3 *Centrality-causal degree diagram method*

2.3 The Hybrid Kano-DEMATEL Model Development and Design Process

Both the Kano model and the DEMATEL method exhibit unique advantages and disadvantages when employed individually for requirements analysis, as illustrated in Table 1. Nevertheless, their integrated use can mutually reinforce each other, thereby aiding decision-makers in determining product requirements development and iteration priorities, particularly when faced with constraints in terms of time, costs, and resources. This integrated approach facilitates the formulation of more precise product development and iteration strategies.

Taking advantage of the advantages of the Kano model and the DEMATEL method, the product function hybrid Kano-DEMATEL Model is established, as shown in Table 4.

The product requirements prioritization strategy involves using the Kano model, which categorizes user needs, as the first criterion, and complementing it with the DEMATEL method, a decision-making tool guided by experts, as the second criterion. This integration constructs a hierarchical model for product requirements prioritization, comprising the following layers: the Goal Layer, the Kano Criterion Layer, the DEMATEL Criterion Layer, and the Requirements Prioritization Table.

The Goal Layer represents the product requirements iteration strategy. The Kano Criterion Layer initially assigns priority levels to the product requirements, following the order of Must-Be > One-Dimensional > Attractive > Indifferent [21], retaining only the Essential Attributes, Expected Attributes, and Exciting Attributes.

The DEMATEL Criterion Layer employs the Centrality-Causality diagram method to identify critical requirements and their interdependencies. Subsequently, it further prioritizes the requirements within the DEMATEL Quadrants, with Quadrant I taking precedence over Quadrant II, which is followed by Quadrant III and Quadrant IV, and within Quadrant I, the requirements are sorted based on their centrality, from high to low [22].

After conducting both qualitative and quantitative dual sorting of all the requirements mentioned above, the Requirements Prioritization Table is established to efficiently convey information regarding requirement priorities and their influence relationships. The specific process is illustrated in Figure 4.

Table 3 *Comparison of advantages and disadvantages of the Kano model and the DEMATEL method*

Research methods	merit	shortcoming
Kano model	Identify and meet customer needs, customer oriented, easy to understand and apply, improve customer satisfaction.	Relying on customer feedback, the classification is not precise enough.
DEMATEL method	Comprehensive analysis, fuzzy processing, visual analysis, suitable for complex problems.	Data demand is high, relies on expert judgment, and is poorly interpretable.

Table 4 *Product function hybrid Kano-DEMATEL Model composition and method*

Level	Target	Research methods
1	User demand acquisition	General induction
2	Demand attribute classification	Kano model
3	Quantification of key requirements impact relationships	DEMATEL analysis
4	Demand sorting	Comprehensive sequencing of product requirements

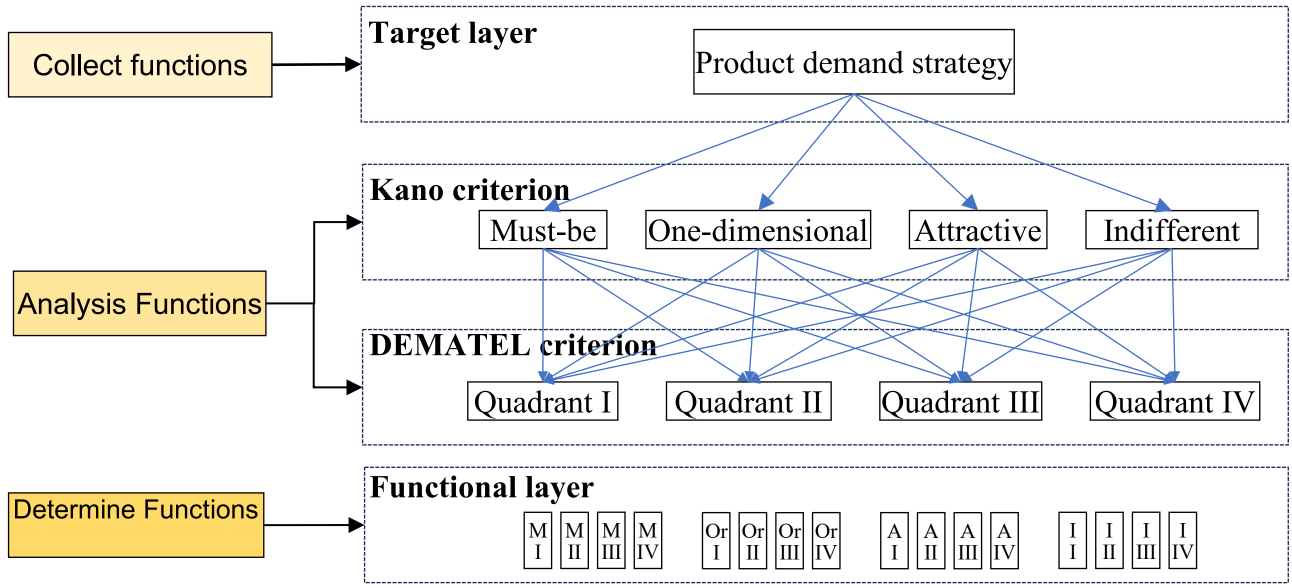

Fig. 4 *Hybrid Kano-DEMATEL model of smart street lamps*

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3. Determination of Functional Attributes of Smart Street Lamps Based on Kano Model

This paper conducts research based on the selection and optimization of smart street lamp functions, and carries out attribute judgment and ranking of smart street lamp functions through functional collection, questionnaire preparation, pre-testing, data collection, data analysis and other steps.

3.1 Functions Collection

Taking Hebi City, Henan Province, China as an example, this paper collects 40 functions of smart street lamps through literature review method and group interview method, and uses F1~F40 to number them, see Table 5. These 40 functional indicators are summarized into two categories: manager functions and user functions according to the different service objects.

3.2 Questionnaire Design

In this study, the questionnaire used for the Kano survey was divided into three main parts. The first part of the questionnaire primarily inquired about the basic characteristics of the respondents, such as gender, age, occupation, and education level. The second part focused on gathering users' general perceptions and design requirements for smart streetlamps. The third part consisted of the Kano questionnaire items, aiming to collect the respondents' objective evaluations of 40 functional indicators related to smart streetlamps, considering both positive and negative aspects.

3.3 Pre-Testing

To enhance the usability and effectiveness of the Kano questionnaire, a preliminary test was conducted with a sample of 24 individuals to facilitate improvements and refinements before its widespread implementation. The test results revealed that the participants demonstrated a clear understanding of the meaning of each question and its corresponding options. Additionally, the reliability coefficient was calculated to be 0.971, and the Corrected Item-Total Correlation (CITC) values exceeded 0.4, indicating a strong positive correlation among the analysis items and reflecting a high level of reliability [23]. These findings confirm the high quality of the questionnaire, making it suitable for subsequent data collection endeavors.

3.4 Data Collection

Data collection is carried out according to the proportion of the population in Hebi, China, and the data collection is carried out online and the tool is questionnaire stars. A total of 330 questionnaires were distributed, 320 were recovered, 7 invalid questionnaires were eliminated, and 313 valid questionnaires were removed, with a recovery rate of 96.97%., with an effective rate of 94.85%.

3.5 Data Analysis

The reliability of the questionnaire was tested by Clonerbach's consistency coefficient by SPSSAU, as shown in Table 6, and the reliability coefficient value was 0.982, which was greater than 0.9, which indicated that the reliability quality of the study data was very high. For the "CITC value", the CITC value of the analysis items is greater than 0.4, indicating that there is a good correlation between the analysis items and a good reliability level [23–25]. The data validity of the questionnaire was analyzed using the KMO and Bartlett tests, see Table 7. The KMO coefficient is greater than 0.8, and the significance probability p value is less than 0.001, and the reliability and validity of the comprehensive judgment questionnaire data are good, and it has a certain authenticity and accuracy [23,25,26].

The frequency analysis of the questionnaire is carried out, and the results of the analysis are shown in Table 8. As can be seen from the table, in terms of gender, the proportion of male and female respondents is balanced. In terms of age, the majority of respondents were young people. In terms of status (occupation), students account for the largest proportion. From the perspective of understanding of smart street lamps, there are relatively many "general" in the sample, with a proportion of 53.35%. From the perspective of satisfaction with the smart street lamps in the area where you work or live, "general" accounts for the highest proportion of 46.65%. It can be seen that residents' understanding and satisfaction with smart street lamps are average.

The satisfaction coefficient Better and the dissatisfaction coefficient Worse of each requirement are calculated by using the Better-Worse coefficient calculation formula in the Kano model, and the 40 functional requirements are decomposed into. There are 3 Must-be functions, 16 One-dimensional functions, 2 Attractive functions, and 19 Indifferent functions. Based on the Better-Worse values, a four-quadrant plot of demand is plotted, as shown in Figure 5. Preliminary ranking of requirements is given as shown in Table 9. For function points in the same quadrant, start with the better coefficient /|Worse coefficient | Size order, the larger the higher.

Table 5 *Smart street lamp function collection*

Numbering	Function	Directly served objects
F1	Switch lamps control	City managers
F2	Intelligent dimming	
F3	Lighting fault monitoring alarm	
F4	Photovoltaic power generation	
F5	5G, WiFi micro base station	
F6	Illegal capture	
F7	Traffic monitoring	
F8	Parking violation alerts	
F9	Occupation of business monitoring	
F10	Monitoring of vegetation conditions	
F11	Municipal facility monitoring	
F12	Rainfall monitoring	
F13	Wisdom to remove smog	
F14	Smart cooling	
F15	Watering wisely	
F16	Meteorological environment monitoring	
F17	Broadcast	
F18	Display screen	
F19	Outdoor advertising	
F20	Face recognition	
F21	Hazard identification	
F22	AI voice alerts	
F23	Emergency call for help	Ordinary residents
F24	EV charging	
F25	Electric bike charging	
F26	Phone charging	
F27	Emergency numbers	
F28	Real-time information on public transport	
F29	Convenient information inquiry	
F30	One-click ride-hailing	
F31	Disability assistance	
F32	Smart trash can	
F33	Direct drinking water supply	
F34	Shared umbrellas	
F35	Bicycle parking	
F36	Integrated donation box	
F37	Integrated point-of-line vendors	
F38	Integrated unmanned beverage machine	
F39	Emergency medication supplies	
F40	Integrated waste collection bin	

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Table 6 *Cronbach α coefficient reliability analysis*

The number of items	Sample size	Cronbach α coefficient
80	313	0.982

Table 7 *KMO and Bartlett tests*

Tests for KMO and Bartlett		
KMO value		0.970
Bartlett sphericity test	Approximate chi-square	17411.641
	df	780
	p	0.000

Table 8 *Frequency analysis results*

Name	Options	Frequency	Percentage (%)	Cumulative percentage (%)
1. Gender	Man	143	45.69	45.69
	Woman	170	54.31	100.00
2. Age	25 years and under	214	68.37	68.37
	26-45 years old	91	29.07	97.44
	46-65 years old	4	1.28	98.72
	66 years and older	4	1.28	100.00
3.Education level	College degree or below	110	35.14	35.14
	Bachelor's degree	137	43.77	78.91
	Master's degree	59	18.85	97.76
	Doctoral degree	7	2.24	100.00
4. The degree of understanding of smart street lamps	Know very well	26	8.31	8.31
	Know quite a bit	60	19.17	27.48
	Know moderately	167	53.35	80.83
	Know very little	39	12.46	93.29
	Completely unfamiliar	21	6.71	100.00
5.Satisfaction with smart street lamps	Very dissatisfied	6	1.92	1.92
	Relatively dissatisfied	10	3.19	5.11
	Generally	146	46.65	51.76
	Relatively satisfied	106	33.87	85.62
	Very satisfied	45	14.38	100.00
Total		313	100.0	100.0

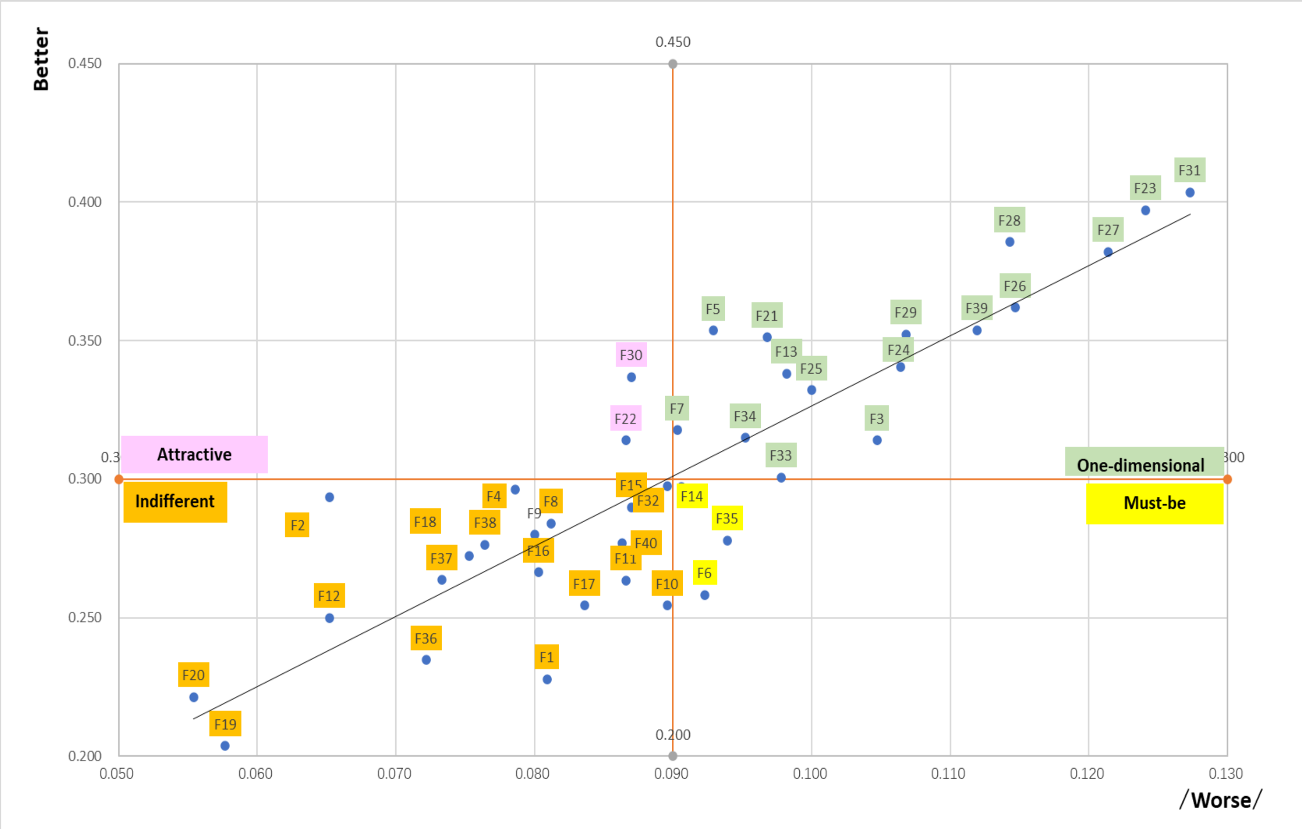

Fig. 5 *Better-Worse analysis of the Kano model of smart street lamp functions*

4. Determination of the Relationship between Demand Influence Based on the DEMATEL Method

In this section, the 21 selected smart street lamp functions from the previous part are evaluated by organizing experts using the DEMATEL (Decision Making Trial and Evaluation Laboratory) method. This approach aims to construct an influence relationship diagram for the functions, thereby considering both their importance and interdependence. Building upon the preliminary ranking of smart street lamp functions based on the Kano model in the previous section, a further optimization of function prioritization is conducted, making it more scientific, comprehensive, and feasible.

4.1 DEMATEL Questionnaire Data Collection

To assess the interrelationships among requirements, three expert users were invited to complete the DEMATEL questionnaire. The panel of experts consisted of one senior smart street lamp designer, one senior civil servant from the smart city management department, and one smart street lamp technology supplier. To ensure the effectiveness of the survey, the three experts underwent training to familiarize themselves with the questionnaire's completion rules. Subsequently, they rated the pairwise interaction scores for the 21 essential, expected, and attractive requirements derived from the Kano survey, resulting in a 21×21 matrix that captured the mutual influence relationships between each pair of requirements.

4.2 DEMATEL Questionnaire Data Processing

By utilizing Equation (5), the comprehensive influence matrix T was derived, and the centrality-causality graph coordinates for the 21 specific requirements were computed, as shown in Table 10. The influence relationships between the individual requirements and their related attributes were visualized using directed arrows, as illustrated in Figure 6. This visualization approach allows decision-makers to gain a more intuitive insight into the critical requirements [27]. Based on the computational and visualized results, it was observed that there are seven functions falling within the first quadrant, two functions in the second quadrant, eight functions in the third quadrant, and four functions in the fourth quadrant, as summarized in Figure 7. In Table 10, the meanings of the various indicators are as follows:

1. Impact degree D value: It represents the comprehensive impact of a certain element on other elements. A higher value indicates a greater degree of influence.

2. Affected degree C value: It represents the comprehensive impact of other elements on a certain element. A higher value implies a greater degree of being influenced.
3. The centrality D+C value: It represents the significance of a certain element within the system. A higher value indicates greater importance of that element.
4. Degree of Cause D-C Value (R): It represents the influence of a certain element on other elements. A value greater than 0 indicates that the element has a greater impact on other elements, making it a causal factor, while a value less than 0 indicates that the element is more influenced by other elements, making it a resultant factor.

From Table 10, it can be observed that the functions with higher comprehensive impact are F5, F30, and F23. The functions most easily affected by other functions are F25, F31, and F39. The functions with higher importance are F23, F30, and F5. The functions categorized as causal factors are F5, F23, F24, F33, F30, and F22, while the other functions belong to resultant factors. Fig. 6 illustrates the comprehensive impact relationships among various functions. It visually presents the influence relationships between different functional elements. The numbers on the arrows represent the magnitude of the impact, with larger numbers indicating a greater influence. In Fig. 6, it is evident that F5, F30, and F23 have a higher number of outgoing arrows with larger associated numbers, indicating that these three functions have a greater comprehensive impact. On the other hand, F25, F31, and F39 have a higher number of incoming arrows with larger numbers, signifying that these three functions are more susceptible to being influenced by other functional factors. The comprehensive impact relationships depicted in Fig. 6 align with the impact relationships shown in Table 10.

Table 9 *Analysis results of KANO model for urban residents' demand for smart street lamp functions*

Numbering	Function	DDI	S	Kano property	Sort
F14	Watering wisely	0.091	0.297	M	1
F35	Face recognition	0.094	0.278	M	2
F6	llegal capture	0.092	0.258	M	3
F31	Occupation of business monitoring	0.127	0.404	O	4
F23	Direct drinking water supply	0.124	0.397	O	5
F28	Integrated unmanned beverage machine	0.114	0.386	O	6
F27	Integrated point-of-line vendors	0.121	0.382	O	7
F26	Integrated donation box	0.115	0.362	O	8
F39	EV charging	0.112	0.354	O	9
F5	5G, WiFi micro base station	0.093	0.354	O	10
F29	Emergency medication supplies	0.107	0.352	O	11
F21	Disability assistance	0.097	0.351	O	12
F24	Shared umbrellas	0.106	0.340	O	13
F13	Smart cooling	0.098	0.338	O	14
F25	Bicycle parking	0.100	0.332	O	15
F7	Traffic monitoring	0.090	0.318	O	16
F34	Outdoor advertising	0.095	0.315	O	17
F3	Lighting fault monitoring alarm	0.105	0.314	O	18
F33	Display screen	0.098	0.301	O	19
F30	Integrated waste collection bin	0.087	0.337	A	20
F22	Smart trash can	0.087	0.314	A	21

Fig. 7 represents the Functional Centrality-Influence Relationship diagram of smart street lamps. The basic meanings of the graph are as follows:

1. The horizontal axis represents centrality (D+C) values, and the vertical axis represents the degree of cause (D-C) values. The two lines in the graph indicate the average values of centrality and the number 0.
2. The first quadrant represents high centrality and high degree of cause, signifying that the element is both important and a causal factor.

3. The second quadrant represents low centrality and high degree of cause, indicating that the element is of low importance but still a causal factor.
4. The third quadrant represents both low centrality and a low degree of cause, implying that the element is of low importance and a resultant factor.
5. The fourth quadrant signifies high centrality and a low degree of cause, meaning the element is important and a resultant factor.

Through Fig. 7, it is evident that the first and second quadrants consist of 6 functions (F23, F30, F5, F35, F33, F22, F24) categorized as causal factors, with the 4 functions in the first quadrant having higher importance. The third and fourth quadrants include F7, F31, F25, F21, F29, F39, F28, F27, F34, F26, F13, and F3, which are considered resultant factors, with functions in the fourth quadrant having higher importance. According to the collation rules of the DEMATEL model (I quadrant> II quadrant> III quadrant> IV. quadrant, sorted by the centrality from high to low in the same quadrant), the specific ranking of 21 street lamp functions is shown in Table 11.

Table 10 *DEMATEL calculates indicator values*

	Impact degree D value	Affected degree C value	The centrality D+C value	Degree of Cause D-C Value (R)
F14	0.945	0.036	0.981	0.909
F35	0.938	0.439	1.376	0.499
F6	0.810	0.755	1.564	0.055
F31	0.278	0.994	1.271	-0.716
F23	1.001	0.488	1.489	0.513
F28	0.191	0.587	0.778	-0.396
F27	0.099	0.680	0.779	-0.581
F26	0.099	0.251	0.350	-0.152
F39	0.000	0.861	0.861	-0.861
F5	1.374	0.000	1.374	1.374
F29	0.424	0.464	0.888	-0.040
F21	0.471	0.595	1.066	-0.124
F24	0.134	0.072	0.206	0.061
F13	0.059	0.188	0.247	-0.129
F25	0.091	1.087	1.178	-0.996
F7	0.737	0.897	1.635	-0.160
F34	0.000	0.437	0.437	-0.437
F3	0.000	0.136	0.136	-0.136
F33	0.709	0.347	1.055	0.362
F30	1.165	0.274	1.439	0.891
F22	0.296	0.231	0.527	0.065

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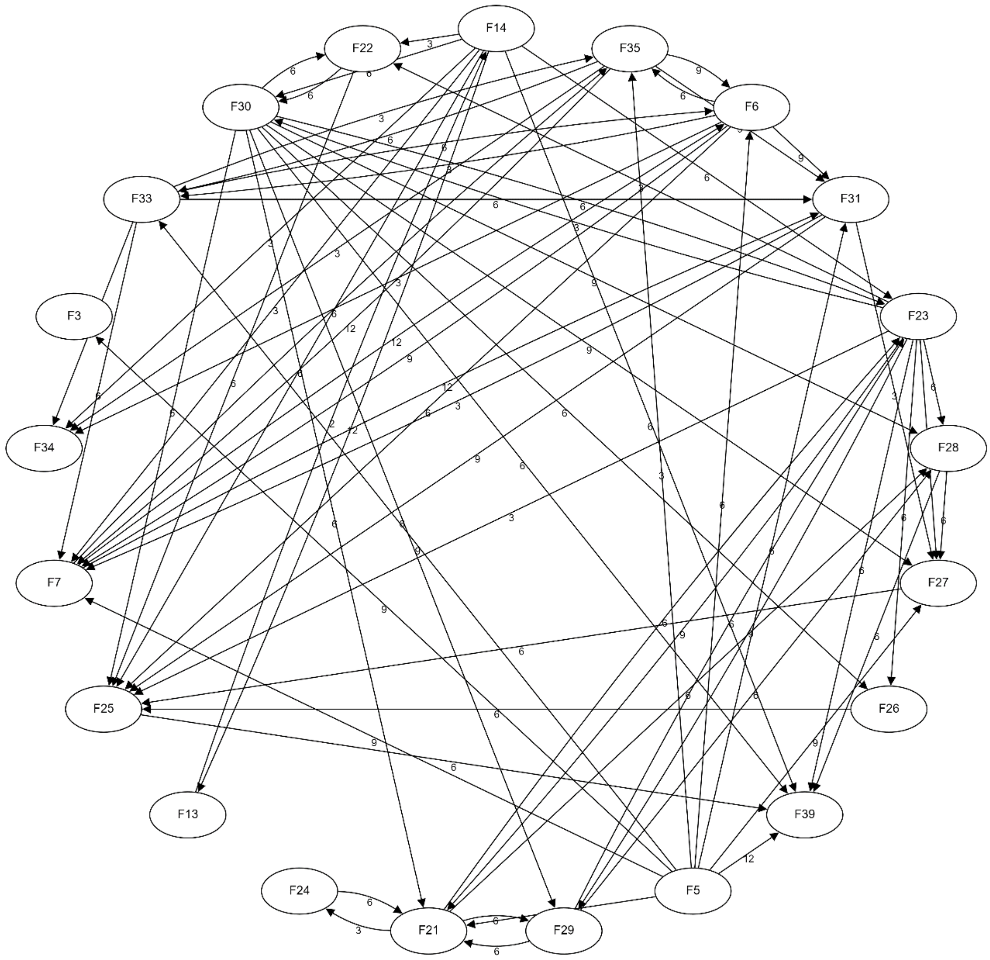

Fig. 6 *Analysis of the functional relationship diagram of each smart street lamp based on the DEMATEL model*

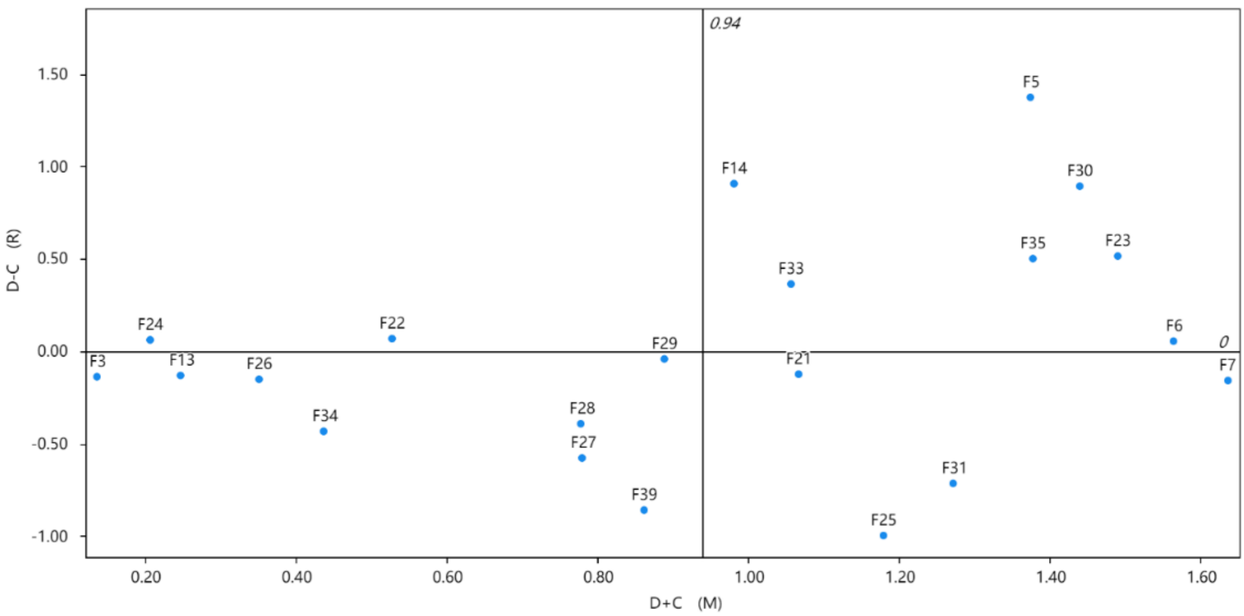

Fig. 7 *Functional centrality-influence relationship diagram of smart street lamps*

4.3 Comprehensive Ranking of Smart Street Lamp Functions Based on Hybrid Kano-DEMATEL Model

Following the rules of hybrid Kano-DEMATEL Model, a comprehensive ranking was conducted by considering the results from both the Kano model and the DEMATEL model. The combined ranking is presented in Table 12. Regarding the three essential attributes F14, F35, and F6, their further sorting was conducted based on the DEMATEL method's Quadrant I > Quadrant II > Quadrant III > Quadrant IV ranking, with priorities determined within each quadrant based on centrality values. After reordering, the results are as follows: F6 ranked first, F35 ranked second, and F14 ranked third. The same sorting approach was applied to the 16 expected attributes, resulting in the comprehensive ranking of the 21 functions as shown in Table 6. During the actual production and installation process, reference can be made to this comprehensive ranking, taking into account the budget and the needs of local residents to selectively implement the functionalities of the smart street lamp system.

Table 11 *Sorting results of the DEMAMEL model of smart street lamp function*

Numbering	Function	DEMEL quadrant	DEMATEL sorting
F6	Illegal capture	I	1
F23	Direct drinking water supply	I	2
F30	Integrated waste collection bin	I	3
F5	5G, WiFi micro base station	I	4
F35	Face recognition	I	5
F33	display screen	I	6
F14	Watering wisely	I	7
F22	Smart trash can	II	8
F24	Shared umbrellas	II	9
F29	Emergency medication supplies	III	10
F39	EV charging	III	11
F28	Integrated unmanned beverage machine	III	12
F27	Integrated point-of-line vendors	III	13
F34	Outdoor advertising	III	14
F26	Integrated donation box	III	15
F13	Smart cooling	III	16
F3	Lighting fault monitoring alarm	III	17
F7	Traffic monitoring	IV	18
F31	Occupation of business monitoring	IV	19
F25	Bicycle parking	IV	20
F21	Disability assistance	IV	21

Table 12 *Ranking of smart street lamp function hybrid Kano-DEMATEL Model*

NO.	Function	Kano property	Kano sorting	Quadrant	DEMATEL sorting	Comprehensive sorting
F14	Watering wisely	M	1	I	7	3
F35	Face recognition	M	2	I	5	2
F6	Illegal capture	M	3	I	1	1
F31	Occupation of business monitoring	O	4	IV	19	17
F23	Direct drinking water supply	O	5	I	2	4
F28	Integrated unmanned beverage machine	O	6	III	12	10
F27	Integrated point-of-line vendors	O	7	III	13	11
F26	Integrated donation box	O	8	III	15	13
F39	EV charging	O	9	III	11	9
F5	5G, WiFi micro base station	O	10	I	4	5
F29	Emergency medication supplies	O	11	III	10	8

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F21	Disability assistance	O	12	Ⅳ	21	19
F24	Shared umbrellas	O	13	II	9	7
F13	Smart cooling	O	14	III	16	14
F25	Bicycle parking	O	15	Ⅳ	20	18
F7	Traffic monitoring	O	16	Ⅳ	18	16
F34	Outdoor advertising	O	17	III	14	12
F3	Lighting fault monitoring alarm	O	18	III	17	15
F33	Display screen	O	19	I	6	6
F30	Integrated waste Collection bin	A	20	I	3	20
F22	Smart trash can	A	21	II	8	21

5. Discussion

Through the application of the hybrid Kano-DEMATEL Model, 21 essential, expected, and attractive functions were selected from the original 40 smart street lamp functions, and a comprehensive ranking of these 21 functions was established. In this section, the advantages of using the hybrid Kano-DEMATEL Model, its application in decision-making for function selection based on specific regional strategies, and the determination of functional priorities will be discussed, providing valuable decision-making reference for the timely construction of smart street lamp projects.

5.1 Advantages of the Hybrid Kano-DEMATEL Model

A comparison between the hybrid Kano-DEMATEL Model in Table 12 and the individual application of the Kano model for ranking reveals the strengths of the hybrid Kano-DEMATEL Model in demand prioritization and gaining insights into key requirements. For instance, in the expected demands, F31 (Occupation Monitoring) and F28 (Integrated Unmanned Beverage Machine) rank higher when using the Kano model alone. However, this approach neglects the influence relationships among the requirements. Through the analysis of centrality and causality using the DEMATEL method, it is evident that these two demands fall under influenced demands, meaning their implementation or enhancement should first address their source demands. Thus, their priority level for development in practice should be adjusted accordingly. Moreover, for the attractive demands identified by the Kano model, such as F30 (Integrated Recycling Bins), the DEMATEL model revealed it to be a core requirement with high centrality and causality. Consequently, considering the enhancement of product attractiveness while maintaining cost control, it might be prudent to transform this demand into a prioritized product feature, thereby increasing user satisfaction.

5.2 Example Analysis of Smart Street Lamp Functions Ranking Results

Because of limited space, the analysis will be demonstrated using three expected demands.

F23 (Direct Drinking Water Supply), positioned in the Expected and Core quadrant (Quadrant I), holds significant potential to enhance the product's competitiveness and simultaneously improve the performance of related functions. With the increasing health awareness among urban residents, carrying one's water bottle has become a new urban trend. However, the issue of water replenishment while outdoors is becoming more prominent, especially in parks or running paths with limited commercial facilities. Integrating this function into smart street lamps will have a considerable impact on user satisfaction.

F22 (Smart Trash Cans), positioned in the Expected and Exciter quadrant (Quadrant II), exhibits strong attractiveness but influences only a few other functions compared to core functions. Although this function is essential for smart street lamps, considering the industry perspective, implementing smart trash cans poses technical challenges and comes with higher costs. Hence, it requires a comprehensive evaluation of costs and benefits, considering the budget and overall development priorities.

F29 (Emergency Medicine Supply), positioned in the Expected and Independent quadrant, has good independence and is not a major focus compared to other demands. Although there are some feedbacks on this requirement during practical usage, satisfying the concentrated demands adequately will suffice. For instance, integrating emergency medicine supply functionality into smart street lamps near parks can address these specific demands and avoid user dissatisfaction due to oversight.

5.3 Function Selection Based on Specific Regional Strategies

During the questionnaire survey, feedback on long-term development suggestions for smart street lamps and functional requirements in different city areas was collected and analyzed, as presented in Table 13 and Table 14. The statistical analysis indicated that 59.42% of the respondents preferred modular upgrades based on technological advancements rather than immediate full functionality. The survey was conducted in the Qibin West District of Hebi City, Henan Province, China, which mainly comprises residential and cultural-educational areas. Based on the statistics, the residents in this region tend to prefer moderately functional smart street lamps with 1-2 unique features. Therefore, when designing the functionalities for smart street lamps in this area, it is essential to follow this iterative strategy, avoiding excessive functions that might lead to waste and reduced resident satisfaction.

The advantage of the hybrid Kano-DEMATEL Model lies in its ability to analyze the iterative strategy for product demands from a holistic perspective, considering the specific characteristics of each requirement and their interdependencies and constraints. It provides valuable insights for product demand iteration but should not be equated with the actual development strategy sequence. In practical cases, further investigation and optimization of relevant influencing factors are necessary, and the development strategy should be adjusted based on specific circumstances.

Table 13 *Long-term development suggestions for smart street lamps*

Options	Subtotal	Proportion
It is recommended that all functions be filled in one step	74	23.64%
It is recommended to replace the latest smart street lamps regularly	52	16.61%
It is recommended to carry out modular upgrades on a regular basis according to technological developments	186	59.42%
other	1	0.32%
This question is valid for filling in the number of people	313	

Table 14 *Statistics on the functional requirements of smart street lamps in different areas of the city*

Title\Options	The function only meets the lighting	Less functional but practical	Moderate functionality, with 1-2 features	Rich and diverse functions to meet different needs
District	71(22.68%)	68(21.73%)	79(25.24%)	95(30.35%)
Business district	44(14.06%)	51(16.29%)	77(24.6%)	141(45.05%)
Bunkyo Diocese	51(16.29%)	53(16.93%)	101(32.27%)	108(34.5%)
residential district	48(15.34%)	74(23.64%)	88(28.12%)	103(32.91%)
High-tech zone	49(15.65%)	46(14.7%)	80(25.56%)	138(44.09%)
Industrial zone	58(18.53%)	83(26.52%)	98(31.31%)	74(23.64%)
suburbs	108(34.5%)	88(28.12%)	61(19.49%)	56(17.89%)

For the construction of smart street lamps in the Qibin West District, where each smart lamppost has limited construction costs, and residents prefer moderately functional street lamps with 1-2 unique features, the development strategy should focus on implementing the 3 essential attributes. As for the expected attributes, the comprehensive ranking results can be used to determine 1-2 distinctive features for each smart street lamp, considering cost savings. For instance, smart street lamps installed near university campuses may prioritize functions like direct drinking water supply and 5G micro base stations, while those near parks or riversides may focus on integrating unmanned beverage machines and small vendor kiosks. Additionally, smart street lamps near residential areas can prioritize features like electric vehicle charging.

During the actual construction process, the government of Qibin District adopted a scheme of alternating installations between regular street lamps and smart street lamps. One smart street lamp was installed at fixed intervals, while the others remained regular street lamps. Additionally, based on specific locations, 1-2 relevant expected attributes were selectively implemented. For regions with less distinct geographic attributes, a cyclic implementation approach was applied to the top 10 smart street lamps' expected attributes based on the comprehensive ranking results. This construction strategy proved to be highly effective, as residents expressed high satisfaction with the newly constructed smart street lamps' functionality.

6. Conclusion

In product function iteration, it is essential to consider the alignment between user demands, organizational resource capabilities, and functionality improvements, and to rapidly identify core requirements among numerous demands. This study combined the Kano model and DEMATEL method to construct a product demand ranking hierarchy model, using smart street lamp development and iteration as an example for demand prioritization research. The research results demonstrate that the use of the DEMATEL method compensates for the Kano model's assumption of independence among product demands, addressing complex, fuzzy, and difficult-to-quantify demands and enhancing the clarity of development and iteration ideas. Visualizations also help decision-makers gain a comprehensive understanding of the interrelationships among demands, identify key requirements more accurately, and improve product iteration efficiency.

Although the study has collected data with broad coverage, there is still room for improvement in obtaining a more comprehensive set of functional demands. Future research could consider incorporating more influencing factors into the model. Additionally, the ranking of functional importance primarily serves as a source of insights for product demand iteration and does not completely dictate the actual product development strategy sequence. Development strategies are influenced by actual technological research and development capabilities, and different regions may have deviations in their specific iteration strategy sequence and focus, requiring differentiation.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Ge Junchao, Go Tze Fong;* ***data collection:*** *Ge Junchao;* ***analysis and interpretation of results:*** *Ge Junchao, Go Tze Fong, Teo Hiu Hong;* ***draft manuscript preparation:*** *Ge Junchao, Teo Hiu Hong. All authors reviewed the results and approved the final version of the manuscript.*

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