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A Study of Regulation Evaluation for the Smart City Planning and Development in the Era of the Internet of Things Based on Weighting Method

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Abstract. The Internet of Things has provided considerable convenience for 5G communications, future technological advancement and development. Taiwan is in a perfect position to develop smart city due to its affluence in natural and human resources, compact geographic features, close proximity to satellite cities, and advantages in geographic size. With a relatively high proportion of factories in the electronics industry, high frequent usage in network, it is motivating and optimistic to plan smart cities for future direction. Employing the various evaluation levels to compare system weights for the establishment and development of smart cities in the era of the Internet of Things, the study conducts a questionnaire survey of scholars and experts and applies the Analytic hierarchy process to rank the construction of smart cities in the era of the Internet of Things. The evaluation system on regulation development explores the order of the impact factors. By evaluating the priority sequence of development plans, the findings of the study promisingly provide a reference for industry development in regulation evaluation system for the smart city construction and development in the era of the Internet of Things.

Keywords: Analytic Hierarchy Process (AHP), smart city, regulations regarding smart city

1 Introduction

This article will define the evaluation of smart city construction and development regulations in the literature review. System evaluation factors, their explanations and their feature descriptions will be introduced in the research methods and procedures of the Analytic hierarchy process (AHP), employing the evaluation results of the calculation weights of the questionnaire calculation and the evaluation outcome. In addition to the analysis, conclusions and suggestions on the results of the evaluation system for smart city establishment and development will be discussed. Taiwan is inhabited by many ethnic groups. In addition to being rich in natural and human resources, it has a small congenital geographic area, close proximity to satellite cities, long and narrow land, a great number of electronics manufacturers. OEM...and other special factors, so the network coverage is particularly outstanding, and it has created related industries and phenomena such as the Internet of Things, 5G communications, and future technology. Due to the aforementioned advantages, the competent authority also plans to take the general construction of smart cities as the future direction and as the motivation for development. However, due to the large scale of development, the associated economic benefits are higher, but the impact on humanities, environment...etc. There is a certain degree of relativity, so how to take into account economic development and various related influences is an extremely important topic.

Regulation Evaluation for the Smart City Planning refers a systematic assessment of the legal and regulatory frameworks governing the planning, implementation, and advancement of smart cities in Taiwan. This eval-

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ua-tion typically involves analyzing the effectiveness, feasibility, and impact of existing policies, identifying chal-lenges, and proposing improvements to ensure sustainable and efficient smart city development. This research would provide certain references for policy makers, researchers, and urban planners refine Taiwan's smart city strategies, ensuring a balance between technological advancement, sustainability, and societal well-being.

2 Smart City Planning and IoT

The smart city conception has gained significant attention as urbanization accelerates worldwide. At the core of smart city development lies the IoT, a network of interconnected devices that collect, transmit, and analyze data to optimize urban functions. By leveraging IoT technologies, cities can enhance operational efficiency, improve public services, and elevate the overall quality of life for residents. Certain integration of IoT in smart cities are highlighted.

First is the Real-Time Data Collection and Analysis. IoT enables the continuous collection of real-time data from various urban systems, including traffic management, energy consumption, air quality monitoring, and waste disposal. By integrating IoT-powered sensors and devices, city administrators can analyze this data to enhance decision-making, improve service delivery, and proactively address urban challenges. Second is the smart infrastructure and transportation. IoT significantly improves urban mobility by optimizing traffic flow, enhancing public transportation systems, and reducing congestion. Intelligent traffic lights, real-time navigation systems, and automated public transport scheduling contribute to smoother and more efficient city travel. Additionally, smart parking solutions leverage IoT to guide drivers to available parking spaces, minimizing traffic bottlenecks and reducing emissions. Third is the energy efficiency and sustainability. A critical aspect of smart city development is sustainability, which is strongly supported by IoT-powered solutions. Smart grids efficiently manage energy distribution by balancing supply and demand, reducing waste, and integrating renewable energy sources. Furthermore, IoT-enabled buildings adjust lighting, heating, ventilation, and air conditioning (HVAC) systems based on occupancy patterns, significantly lowering energy consumption and operational costs. Then is the public safety and security. IoT enhances urban security through automated surveillance systems, emergency response mechanisms, and predictive crime analytics. Smart surveillance cameras equipped with real-time monitoring and facial recognition can help detect suspicious activities, while IoT-powered emergency alert systems improve disaster response. Additionally, smart streetlights equipped with motion sensors not only enhance security but also contribute to energy conservation. Final point is the citizen engagement and smart governance. IoT fosters greater citizen participation in governance by enabling real-time communication between residents and city administrators. Mobile applications allow individuals to report infrastructure issues, such as potholes or water leaks, while also receiving updates on city services. Moreover, data-driven governance platforms utilize IoT-generated insights to inform policy decisions, allocate resources efficiently, and improve service delivery. These provided the importance of smart city planning weighting method to the IoT evolutions.

3 Literature Review

In addition to conservation of local culture and ecological environment, the laws and regulations evaluation system on development and establishment of smart city should also consider the reduction of interference with the local and traditional culture. The regulation evaluation system should follow certain criteria: 1. They should not violate traditional cultural values. 2. They should provide convenience for customers. 3. They should enable users power over operation, management and manipulation of resources. 4. They should provide cultural resources conservation including cultural assets, relics, territories and other cultural resources and integration with ecological resources. In this study, the factors evaluated have been summarized in the literature review, expert interviews, and brainstorming methods to summarize the levels, evaluation dimensions, factors, explanations, and feature descriptions in the evaluation system of smart city construction and development under the Internet of Things, as shown in Table 1.

Table 1. Explanations and categorizations of dimensions and factors for smart city evaluation

Assessment dimension	Factors	Explanation and categorizations
D1 Social factor	D1-1 The number of residents	The residents expected to live, move, and work in the area after the development is calculated after the development is established. The newly-arrived residents will affect national taxation after the establishment and the development of smart cities.
	D1-2 The age of residents	The age of residents expected to live, move, and work in the area after the development is calculated after the development is established.
	D1-3 Remodulation	After the development is set up, some change due to residents' activity, migration, and socialization, remodulation is expected in the area
	D1-4 The health of residents	After the establishment of the development, the activity, the migration, and socialization of the population will affect the health of the population
	D1-5 The life of the underprivileged	After the establishment of the development, the activity, the migration, and socialization of the population will affect the health of the population. The life of the underprivileged
D2 Economic factor	D2-1 Taxation	The newly-arrived residents will affect national taxation after the establishment and the development of smart cities.
	D2-2 Food security	The number of changes in the newly-arrived residents and the space of their industries will affect food security after the establishment and the development of smart cities.
	D2-3 Agriculture, forestry, fishery and animal husbandry.	The number of changes in the newly-arrived residents and the space of their industries will affect the industry chain of agriculture, forestry, fishery and animal husbandry after the establishment and the development of smart cities.
	D2-4 Employment	The number of changes in the newly-arrived residents and the space of their industries will affect employment after the establishment and the development of smart cities.
	D2-5 Levy on land tax	The number of changes in the newly-arrived residents and the space of their industries will affect levy on land tax after the establishment and the development of smart cities.
	D2-6 Financial expenditure on public facilities	The number of changes in the newly-arrived residents and the space of their industries will affect financial expenditure on public facilities after the establishment and the development of smart cities.
	D2-7 The complete use of land	The number of changes in the newly-arrived residents and the space of their industries will affect the complete use of land after the establishment and the development of smart cities.
D3 Cultural and ecological factors	D3-1 Conservations of rural areas	The new-built construction and various public facilities will affect the conservation of the rural areas after the establishment and the development of smart cities.
	D3-2 Conservations of cultural relics	The new factories and industrial establishment will affect the conservation of the cultural relics after the establishment and the development of smart cities.
	D3-3 Life conditions and life styles	The new factories and industrial establishment will affect life conditions and life styles of the residents after the establishment and the development of smart cities.
	D3-4 Conservations of ecological environment	The new factories and industrial establishment will affect the conservation of ecological environments after the establishment and the development of smart cities.
	D3-5 Life of people in the neighborhood	The new factories and industrial establishment will affect the life of people in the neighborhood after the establishment and the development of smart cities.
	D3-6 The whole society	The new factories and industrial establishment will affect the whole society after the establishment and the development of smart cities.
D4 Sustainability factor	D4-1 The sustainable development of the nation	The residents and their future generations will be able to enjoy a comfortable and diverse ecological environment after the establishment and the development of smart cities.
	D4-2 Prosperity and comfort	The society will offer a safe, prosperous, and harmonious living environment after the establishment and the development of smart cities
	D4-3 Land conservation of the nation	To pursue the goal of sustainable development of the nation, climate stability, national land security, natural environment preservation and allocation of resources and industries, and the national land integration management should be ensured after the establishment and the development of smart cities.

4 Methods

Multi-criteria decision making has broad applications, including in the selection and development of suppliers [1], IT management decisions [2], and stock options [3]. Ordering application methods include the Delphi Method, SAW (Similarity aggregation Method), Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), and Analytic hierarchy process (AHP). When rating alternatives, they must be assumed to be independent and rank should be preserved. When comparing alternatives, they must be assumed to be dependent and rank may not always be preserved [4]. This study uses the AHP as the application method and assumes that each assessment criterion is independent. The AHP has been used in diverse applications including the development of strategies. In the current study [5], the AHP literature was extended by addressing the necessity of prioritizing numerous alternatives exhibiting high heterogeneity [6-8]. The AHP has many advantages over other analysis methods in that it facilitates simplifying complex decision-making problems by decomposing them into hierarchies, and it is simple enough to be understood by nonprofessionals. Therefore, in this study, we examined the validity of the AHP in evaluating the sustainability of international hot Spring tourist hotels on indigenous lands. Generating priorities through an organized decision-making process entails breaking down a decision into several hierarchies according to the following steps [9].

1. Define of the decision problem.
2. Identify of the actors involved.
3. Establish a hierarchical framework.
4. Design of a questionnaire. This step enables obtaining a paired comparison matrix A. If n factors are compared, then the number of paired comparisons that must be conducted is $n(n-1)/2$. Because of the reciprocal property of paired comparisons, if the ratio between elements i and j is aij, then the ratio between elements j and i is $1/aij$. Similarly, the lower triangular matrix of the paired comparison matrix A is the reciprocal of the upper triangular matrix, as shown in equation (1):

$$A=\left[a_{ij}\right]=\begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & & \cdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}=\begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \cdots & \cdots & & \cdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \tag{1}$$

where Wi represents the element weight of i; $i = 1, 2, \ldots, n$
aij represents the relative importance ratio between elements, i=1, 2, …, n; j=1, 2, …, n

5. Calculate the eigenvalue and eigenvector. The geometric mean can be obtained by multiplying elements in every row and then normalizing the value, as expressed in equation (2).

$$W_i=\frac{\left(\prod_{j=1}^{n}a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n}a_{ij}\right)^{\frac{1}{n}}},i,j,=1,2,\ldots,n \tag{2}$$

A new eigenvector, Wi, is derived by multiplying the paired comparison matrix A with the obtained eigenvector Wi. Moreover, λmax is obtained by dividing every vector of Wi by the corresponding original vector Wi, and then calculating the arithmetic mean of every derived value:

$$\lambda_{\max}=\frac{1}{n}\left(\frac{W_1^{'}}{W_1}+\frac{W_2^{'}}{W_2}+\ldots\frac{W_n^{'}}{W_n}\right) \tag{3}$$

6. Execute a consistency test. This step involves conducting a consistency test to determine the consistency index (*C.I.*), as expressed in equation (4). Saaty suggested that the most satisfactory *C.I.* is <0.1 and that the highest allowable bias is *C.I.* < 0.2; if the *C.I.* falls within this range, consistency is ensured. This is expressed as follows:

$$C.I. = \frac{\lambda_{\max} - n}{n-1} \tag{4}$$

where, λmax = the greatest eigenvalue of Matrix A, and n= the number of assessment elements.
In matrices of the same order, the *C.I.* value-to-*R. I.* value ratio is referred to as a consistency ratio (*C. R.*), as shown in Formula (5).

$$\text{C. R.} = \frac{\text{C. I.}}{\text{R. I.}} \tag{5}$$

If *C.R.* < 0.1, matrix consistency is satisfactory. All assessment criteria of the same level were evaluated using paired comparisons based on an assessment of the elements from the level above them and rated using a scale from 1 to 9 (Table 2).

Table 2. The fundamental scale of absolute numbers

Intensity of importance	Definition	Explanation
1	Equal importance of *i* and *j*	Two activities contribute equally to the objective
3	Moderate importance of *i* over *j*.	Experience and judgment slightly favor one activity over another
5	Strong importance of *i* over *j*	Experience and judgment strongly favor one activity over another
7	Very strong importance of *i* over *j*	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance of *i* over *j*	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise Judgment numerically because there is no good word to describe it.

The positive reciprocal matrices produced from assessment scales 1–9 produce different *CI* values under different orders, and are referred to as the random index (*RI*). The *CI* value-to-*RI* value ratio under the same order matrix is referred to as the *CR* value. Here, each *RI* value is an average random consistency indicator. The RI value of each order is as shown by the average random consistency index in Table 3 [10].

Table 3. Average random consistency index

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

In addition, when the importance of each order differs, the consistency of the entire level structure may need to be tested. As such, when a level structure possesses more than two levels, the consistency ratio of the hierarchy (CRH) must be considered. However, this step may be omitted if a weighting system is established. Because this study does not require the consideration of relative importance between different levels, CRH testing is omitted.

5 Results and Analyses

The study aims to investigate factors that influence the evaluation and the regulation systems for the smart city development. Our findings have revealed the most important emphasis of the weights on the specific factors by means of calculating their weight and index. There are three levels in this evaluation system. To begin with, the first level, also called the target level, is our aim for the study, the evaluation system for smart city development. Next, the second level, in which the four dimensions are involved in the system, including D1 dimension of social factor, D2 dimension of economic factor, D3 dimension of cultural and ecological factors, and D4 dimension of sustainability factor. Last but not the least, the third level, the detailed factors involved in each category, consists of 21 relevant factors. Specifically, dimension 1 includes five relevant factors, including D1-1. The number of residents, D1-2 The age of residents, D1-3 Remodulation, D1-4. The health of residents, and D1-5. The life of the underprivileged. Furthermore, dimension 2 includes seven relevant factors, including D2-1Taxation, D2-2 Food security, D2-3 Agriculture, forestry, fishery and animal husbandry, D2-4 Employment, D2-5 Levy on land tax, D2-6 Financial expenditure on public facilities, and D2-7. The complete use of land. What's more, dimension 3 includes six factors, including D3-1 Conservations of country sides, D3-2 Conservations of cultural relics, D3-3 Life conditions and life styles, D3-4 Conservations of ecological environments, D3-5 Life of people in the neighbor, and D3-6. The whole society. Finally dimension 4 includes three factors, including D4-1. The sustainable development of the nation, D4-2 Prosperity and comfort, and D4-3 Land conservation of the nation. All in all, 21 factors, considered as evaluation indicators, are described and evaluated in this study. The overall evaluation dimension and evaluation factor are as shown in Fig. 1. In what follows, the hierarchical analysis of the evaluation system is shown in the following figure. Fig. 1 introduces the four hierarchies, different factors evaluated, and descriptions of various factors under each category.

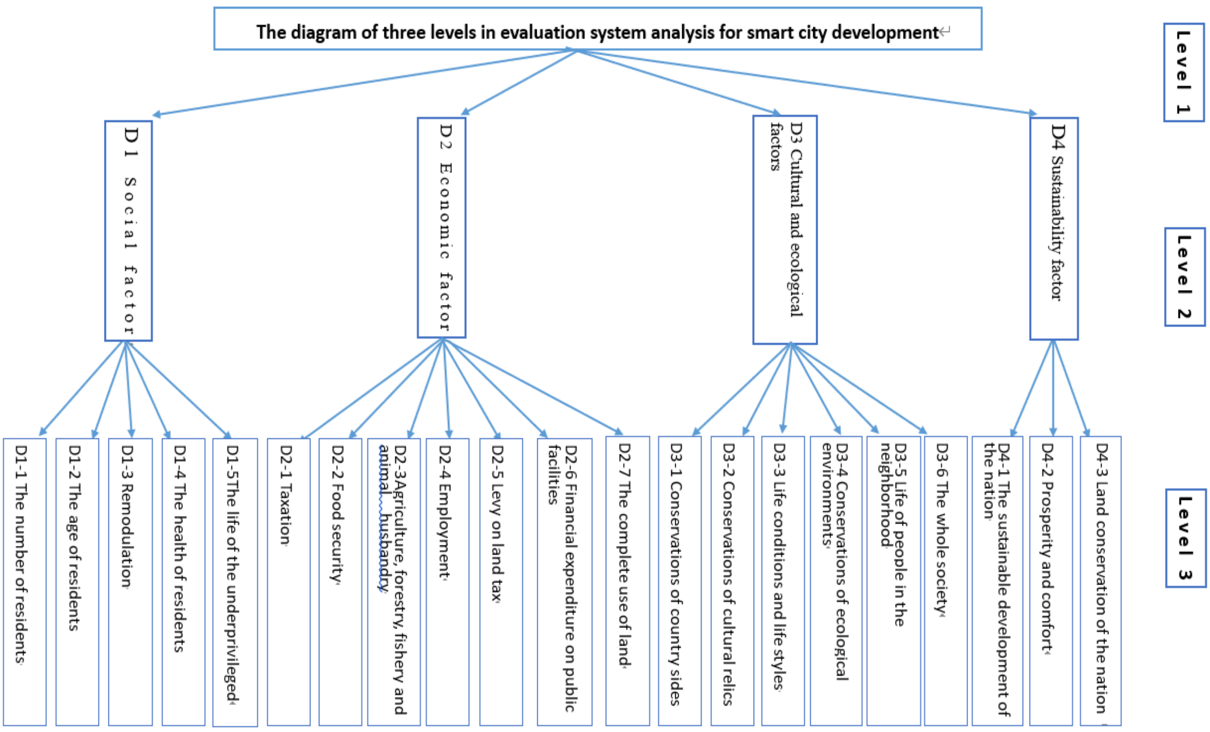

Fig. 1. The diagram of three levels in evaluation system analysis for smart city development

The expert questionnaire invites 12 experts and scholars, 4 from the public sector; 4 from the industry, local opinion leaders, and planning agencies; 4 from the academic fields with expertise in environmental landscape and regional development, and 12 experts and scholars on AHP measurement. The methods have a certain degree of understanding, and one-to-one questionnaires are completed through focus discussion and in-depth interviews.

The details are shown in the design of the paired comparison questionnaire.

Table 4. Paired comparison questionnaire design (with land use as an example)

Dimension category	Absolutely important	Extremely important	Very important	Moderately important	Equally important	Moderately unimportant	Very unimportant	Extremely unimportant	Absolutely unimportant	Compared items
	9	7	5	3	1	3	5	7	9	
D1 Social facto	□	□	□	□	□	□	□	□	□	D2 Economic factor
	□	□	□	□	□	□	□	□	□	D3 Cultural and ecological factors
	□	□	□	□	□	□	□	□	□	D4 Sustainability factor
D2 Economic factor	□	□	□	□	□	□	□	□	□	D3 Cultural and
	□	□	□	□	□	□	□	□	□	D4 Sustainability factor
D3 Cultural and ecological factors	□	□	□	□	□	□	□	□	□	D4 Sustainability factor

The expert questionnaires were processed through group decision making (using geometric means) to construct assessment element pairwise comparison matrices. The results of the assessment element matrix weight calculation using the assessment elements under “land use” are shown in Table 5.

Table 5. Weight calculation example: matrix of assessment elements under land use

	D 1	D 2	D 3	D 4
D 1	1.00	2.08	1.76	1.69
D 2	0.48	1.00	1.03	0.83
D 3	0.57	0.97	1.00	1.10
D 4	0.59	1.20	0.91	1.00
Weight	0.378	0.193	0.213	0.216

In this study, we invited 12 experts, including four relevant government employees, four private construction owners and four academic professors from well-known university department of archaeology and civil engineering to take part in in-depth discussion panels and one-on-one interviews. These experts were also asked to fill out the questionnaire. The calculation of geometric means, the evaluation of paired comparison matrix of evaluation factors and the calculation of C.I. and C.R. of the questionnaire were quite satisfactory, matching the requirement of consistency. Details of evaluation and weight orders are listed in Table 6.

Table 6. The results of weight orders of all items

Items	Items weights	Items orders	Factors	Factor weight	Factors orders	Combined weights	General order
D1 Social factor	0.059	4	D1-1 The number of residents	0.174	3	0.04797	12
			D1-2 The age of residents	0.046	5	0.01276	17
			D1-3 Remodulation	0.047	4	0.01285	16
			D1-4 The health of residents	0.320	1	0.08839	2
			D1-5 The life of the underprivileged	0.281	2	0.07755	5

D2 Economic factor	0.069	3	D2-1 Taxation	0.055	5	0.01516	14
			D2-2 Food security	0.220	1	0.06074	8
			D2-3 Agriculture, forestry, fishery and animal husbandry	0.201	2	0.05545	9
			D2-4 Employment	0.199	3	0.05491	10
			D2-5 Levy on land tax	0.036	6	0.00986	20
			D2-6 Financial expenditure on public facilities	0.035	7	0.00967	21
			D2-7 The complete use of land	0.178	4	0.04902	11
D3 Cultural and ecological factors	0.332	2	D3-1 Conservations of country sides	0.279	3	0.07701	6
			D3-2 Conservations of cultural relics	0.288	1	0.07941	3
			D3-3 Life conditions and life styles	0.052	4	0.01425	15
			D3-4 Conservations of ecological environments	0.284	2	0.07832	4
			D3-5 Life of people in the neighborhood	0.042	5	0.01156	18
			D3-6 The whole society	0.038	6	0.01060	19
D4 Sustainability factor	0.464	1	D4-1 The sustainable development of the nation	0.539	1	0.14878	1
			D4-2 Prosperity and comfort	0.229	2	0.06313	7
			D4-3 Land conservation of the nation	0.082	3	0.02262	13

6 Conclusion

The results of this study show that the comparative research dimension of the weight of the connotation system for the evaluation of laws and regulations for the establishment and development of smart cities has constructed four evaluation dimensions and 21 evaluation indexes, and can compare the differences of the evaluation results when the weights of each dimension are different. Among the four dimensions, the weight quality of "D4 sustainable development factor" is 0.464. Details of evaluation and weight orders are listed in Table 7.

Table 7. The results of weight orders of all items results four evaluation dimension

Items	Items weights	Items orders
D1 Social factor	0.059	4
D2 Economic factor	0.069	3
D3 Cultural and ecological factors	0.332	2
D4 Sustainability factor	0.464	1

Among the factors under each dimension, the "D1-4 The health of residents "under the "D1 social factor" dimension accounts for 0.320 of this category, and the weight quality is the highest. Among the "D2 economic factors", the "D2-2 food security" accounts for 0.220 of this category, and the weight quality is the highest. The "D3-2 Conservations of cultural relics "under the "D3 cultural and ecological factors" dimension accounts for 0.228 of this category, with the highest weight. Among the "D4 sustainability factor", the "D4-1The sustainable development of the nation" accounts for 0.539 of this category, and the weight is the highest, indicating that the most important and the priority aspects of local "surrounding health", "food security", "cultural relics" and "sustainable development" are the evaluation and application of land expropriation in the establishment of business plans. In order to avoid disputes, we must still respect the opinions of local people. Details of evaluation and weight orders are 21 evaluation indexes listed in Table 8.

Table 8. The results of weight orders of all items results four evaluation dimension 21 evaluation indexes

Items	Factors	Factor weight	Factors orders
D1 Social factor	D1-1 The number of residents	0.174	3
	D1-2 The age of residents	0.046	5
	D1-3 Remodulation	0.047	4
	D1-4 The health of residents	0.320	1
	D1-5 The life of the underprivileged	0.281	2
D2 Economic factor	D2-1 Taxation	0.055	5
	D2-2 Food security	0.220	1
	D2-3 Agriculture, forestry, fishery and animal husbandry	0.201	2
	D2-4 Employment	0.199	3
	D2-5 Levy on land tax	0.036	6
	D2-6 Financial expenditure on public facilities	0.035	7
	D2-7 The complete use of land	0.178	4
D3 Cultural and ecological factors	D3-1 Conservations of country sides	0.279	3
	D3-2 Conservations of cultural relics	0.288	1
	D3-3 Life conditions and life styles	0.052	4
	D3-4 Conservations of ecological environments	0.284	2
	D3-5 Life of people in the neighborhood	0.042	5
	D3-6 The whole society	0.038	6
D4 Sustainability factor	D4-1 The sustainable development of the nation	0.539	1
	D4-2 Prosperity and comfort	0.229	2
	D4-3 Land conservation of the nation	0.082	3

Thus, it is suggested that expectations and proposals of local people are considered as well. It is recommended that for future follow-up, researchers can expand the evaluation dimensions and factors according to different evaluation aspects, work collaboratively with the decision-making groups of experts from the central government, different regional organizations so as to analyze the differences of factors on the evaluation dimensions and index weights.

This study explores the profound significance of Taiwan's smart city development in the era of the Internet of Things (IoT). By examining the background and benefits of this topic, it aims to provide valuable insights into shaping the future of urban development.

Traditional research methods may suffer from key limitations, such as a lack of systematic and quantitative analysis, potentially leading to biased or subjective results. To address this issue, this study adopts expert interviews and questionnaires as part of the literature review and introduces an efficient research methodology—the Analytic Hierarchy Process (AHP). This method enables the collection of reliable data through questionnaires and the calculation of accurate weightings, ensuring a more rigorous and comprehensive analysis.

Furthermore, this study identifies and elaborates on various critical factors influencing smart city development, including healthcare, food safety, and sustainability. These factors align with the research objectives, reinforcing the significance and relevance of the study.

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