Research on Key Influence Factors of Sustainable Development Capability of Smart City Based on Hybrid Decision Model

Yuantao Huang1*, Yingtong Hu1
1 School of Economics & Management, Harbin Institute of Technology, Weihai, Shandong, 264200, China.
*Corresponding author’s e-mail: 20s030225@stu.hit.edu.cn

Abstract. The development of economy and the progress of human society are urging the pace of urban development. The combination of urban services, information and communication technologies has given birth to smart cities. In the long-term construction process, the sustainable development capacity of smart cities is weak. In order to enhance the sustainable development capability of smart cities, we establish an indicator system of factors affecting the sustainable development of smart cities and use decision-making trial and evaluation laboratory (DEMATEL) and analytic network process based on DEMATEL (D-ANP) to analyze the interrelationships and relative importance of influence factors. The results reveal that in the evaluation index system of smart city sustainability development, Smart governance (D2) has the greatest impact on other dimensions. As for the impact on the sustainable development of smart cities, the influence of smart city mechanism (D3) has the largest weight, smart people's livelihood (D1) and Smart governance (D2) have similar weights. Based on the results, suggestions for improvement are provided for the sustainable development of smart cities.

1. Introduction
The concept of smart city originated from the "Smart Earth" proposed by IBM, which advocates the application of a new generation of information technology to all walks of life in the city. In the information age, information technology continues to improve, and its relating applications are widely popularized. The application of advanced information technology has greatly promoted the development and construction of smart cities. Since the 1990s, European and American countries have taken the lead in the research and practice of smart cities, hoping to improve the efficiency of city operation and management through information and communication technology. China proposed the construction of smart cities in 2009. In 2013, the first batch of pilot smart cities implemented by the Ministry of Housing and Urban-Rural Development entered a stage of rapid development.

The concept of sustainable development was first formally put forward in the Human Environment Conference held by the United Nations in 1972. In 1987, the Butland Report published by the World Commission on Environment and Development defined it as: “Development that not only satisfies the needs of contemporary people, but does not endanger the ability of future generations to meet their needs.” Sustainable development of smart cities is required to use information technology to improve the level of urban intelligence and develop the city’s economy, while taking into account the protection of city resources and the environment, so as to realize a kind of ecosystem construction.
The smart city operators should take intelligence as the brain and carries out system control, coordination and integration from top to bottom[2].

However, for a long time, the construction and development of smart cities has only focused on the development of information technology and the construction of infrastructure[3-4]. There are still problems such as poor data sharing capabilities and low resource coordination during smart cities’ development. In addition, with the gradual improvement of the level of urban intelligence and the rapid development of urban economy, the waste of urban resources and environmental pollution are becoming more and more serious, which are not in line with the concept of sustainable development. In order to meet the requirements of sustainability, the development of smart cities should not only focus on the application of high-tech and related technology infrastructure construction, but should also focus on the linking of "people and things-resources-technology-information data-environment” in smart cities and issues of synergy and protection[5]. This article will explore the influencing factors that affect the sustainable development of smart cities, and use decision-making trial and evaluation laboratory (DEMATEL) and analytic network process based on DEMATEL (D-ANP) to analyse the internal relationships of influence factors in-depth, so as to help decision-makers make relevant policy formulations, and improve the efficiency of management and the ability of smart cities’ sustainable development.

2. Evaluation index system
This article adopts the principles of concise, science, comparability, operability, measurability, dynamics and systematism to construct the evaluation index system. Through literature analysis and expert inquiries, a smart city sustainability evaluation index system, which include three dimensions and ten factors, has been established. Smart people's livelihood (D1)[6] includes four factors: Medical service (C1), Education service (C2), Social insurance (C3) and Community Building (C4), reflecting the humanistic thoughts that pay attention to “people and things” in the development of smart cities; Smart governance (D2)[7-8] includes four factors: Smart transportation (C5), Smart environment (C6), City safety (C7) and City information (C8), reflecting the consideration of resources, technology, information, and the environment in the process of smart city governance; The smart city mechanism (D3)[9] includes two factors: Institutional mechanism (C9), Safety assurance system (C10), taking into account the complex urban environment in the development of smart cities. The evaluation index system of the sustainable development capability of smart cities is shown in Table 1.

Table 1. A slightly more complex table with a narrow caption.

| Dimension       | Criteria               | Examples                                                                 |
|-----------------|------------------------|-------------------------------------------------------------------------|
| Smart people's  | Medical service C1     | The situation and proportion of medical institutions that have established electronic medical records; The situation and proportion of medical institutions that achieve online medical treatment and appointment registration. |
| livelihood D1   | Education service C2   | The situation and proportion of schools with multimedia teaching equipment; The situation and proportion of school’s wireless network coverage. |
|                 | Social insurance C3    | Networking of insurance in different places and networking of employment. |
|                 | Community Building C4  | Online booking rate and community information push rate of housekeeping service platform; Utilization rate of e-payment for public. |
| Smart governance D2 | Smart city transportation C5 | Transportation services, bus informatization reporting service, and smart adjustment of urban traffic posts. |
|                 | Smart city environment C6 | The situation and coverage rate of air, water, noise real-time monitoring; The situation and coverage rate of automatic |
3. Methodology
On the basis of the established influence factor index system, we use hybrid decision model for in-depth analysis. This model includes two techniques: decision-making trial and evaluation laboratory (DEMATEL) and DEMATEL based analytic network process (D-ANP)\[10-11\]. The model, which can be applied to complex situations in real problems, considers the various dimensions of influence factors and the interaction among them.

The technique of DEMATEL is used to calculate the total influence matrix and construct the influential network relationship map (INRM). Based on total influence matrix obtained from DEMATEL, ANP is used to calculate the weight of each factor.

3.1. Decision-making trial and evaluation laboratory
The analysis steps of the DEMATEL are as follows:

(1) determine the initial score of the relationship between the factors
The initial score is obtained from seven experts who have practical experience in smart city. The degree of each factor’s interaction is measured by the scale from 0-4: 0 indicates no influence; 1 indicates low influence; 2 indicates medium influence; 3 indicates high influence, and 4 indicates very high influence.

(2) Obtain the direct influence matrix
After getting the degree of the factor’s interaction, the degree is represented in the form of matrix, namely direct influence matrix.

\[
M = \begin{bmatrix}
0 & m_{12} & m_{13} & \cdots & m_{1n} \\
m_{21} & 0 & m_{23} & \cdots & m_{2n} \\
m_{31} & m_{32} & 0 & \cdots & m_{3n} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
m_{n1} & m_{n2} & m_{n3} & \cdots & 0
\end{bmatrix}
\] (1)

(3) Normalization of matrix \(M\) to obtain the normalized matrix \(N\)
The direct influence matrix \(M\) is normalized, so that the value of each element of the normalized matrix \(N\) is between 0-1.

\[
\text{Maxvar} = \max (\max (\sum_{j=1}^{n} m_{ij}), \max (\sum_{i=1}^{n} m_{ij}))
\]

\[
N = M / \text{Maxvar}
\] (2) (3)

(4) Calculate the total matrix \(T\)
\[
T = (N + N^2 + N^3 + \cdots + N^n) = N(I - N)^{-1}
\]

\[
T = \begin{bmatrix}
t_{11} & t_{12} & t_{13} & \cdots & t_{1n} \\
t_{21} & t_{22} & t_{23} & \cdots & t_{2n} \\
t_{31} & t_{32} & t_{33} & \cdots & t_{3n} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
t_{n1} & t_{n2} & t_{n3} & \cdots & t_{nn}
\end{bmatrix}
\] (4) (5)

(5) Construct the influential network relationship map
The sum of row and column of the total matrix \( T \) are calculated. The influential network relation map (INRM) is established with \( (r_i + c_j) \) centrality as abscissa and \( (r_i - c_j) \) causation degree as ordinate.

\[
R = [r_{1:n \times 1}] = [\Sigma_{j=1}^{n} t_{ij}] (i = 1, 2, 3, ..., n) \tag{6}
\]

\[
C = [c_{1:n}] = [\Sigma_{i=1}^{n} t_{ij}] (j = 1, 2, 3, ..., n) \tag{7}
\]

3.2. Network analytic process

The steps of using the total influence matrix \( T \) obtained from DEMATEL to calculate the influence weight through network analysis process (ANP) are as follows:

(1) Normalized the total influence matrix \( T \)

The total influence matrix \( T \) is normalized from the perspectives of dimension \( (T_D) \) and factor \( (T_C) \).

If \( T_C \) is normalized in Dimension \( D_1 \), the influence matrix of \( D_1 - D_1 \) is expressed as follows:

\[
T_{C_1}^{T_1} = \begin{bmatrix} C_1 & C_2 & C_3 & C_4 \\ C_1 & t_{11}^{C_1} & t_{12}^{C_1} & t_{13}^{C_1} \\ C_2 & t_{21}^{C_1} & t_{22}^{C_1} & t_{23}^{C_1} \\ C_3 & t_{31}^{C_1} & t_{32}^{C_1} & t_{33}^{C_1} \\ C_4 & t_{41}^{C_1} & t_{42}^{C_1} & t_{43}^{C_1} \end{bmatrix}
\]

(9)

The sum value of matrix row in dimension is

\[
d_i = \sum_{j=1}^{n} t_{ij} \tag{10}
\]

Consequently, \( T_{C_1}^{T_1} \) is:

\[
T_{C_1}^{T_1} = \begin{bmatrix} C_1 & C_2 & C_3 & C_4 \\ D_1 & t_{11}^{D_1} & t_{12}^{D_1} & t_{13}^{D_1} \\ t_{21}^{D_1} & t_{22}^{D_1} & t_{23}^{D_1} \\ t_{31}^{D_1} & t_{32}^{D_1} & t_{33}^{D_1} \\ t_{41}^{D_1} & t_{42}^{D_1} & t_{43}^{D_1} \end{bmatrix}
\]

(11)

Similarly, \( T_D \) is normalized as follow:

\[
T_D = \begin{bmatrix} D_1 & D_2 & D_3 \\ t_{11}^{D_1} & t_{12}^{D_1} & t_{13}^{D_1} \\ t_{21}^{D_1} & t_{22}^{D_1} & t_{23}^{D_1} \\ t_{31}^{D_1} & t_{32}^{D_1} & t_{33}^{D_1} \end{bmatrix}
\]

(12)

The sum value of the matrix rows is

\[
d_i = \sum_{j=1}^{n} t_{ij} \tag{13}
\]

And the normalized \( T_{D}^{g} \) is
(2) Calculate the unweighted super matrix

\[ T_D = \begin{bmatrix} D_1 & D_2 & D_3 \\ D_1 & D_2 & D_3 \\ D_3 & D_2 & D_1 \end{bmatrix} \]

\[ T_D = \begin{bmatrix} t_{11}^{11} & t_{11}^{12} & t_{11}^{13} \\ t_{12}^{11} & t_{12}^{12} & t_{12}^{13} \\ t_{13}^{11} & t_{13}^{12} & t_{13}^{13} \end{bmatrix} \]

(14)

(2) Calculate the unweighted super matrix

\[ W = \begin{bmatrix} W_{11} & W_{12} & W_{13} \\ W_{21} & W_{22} & W_{23} \\ W_{31} & W_{32} & W_{33} \end{bmatrix} \]

(15)

Where \( W_{11} = \begin{bmatrix} a_{11}^{11} \\ a_{12}^{11} \\ a_{13}^{11} \\ a_{21}^{11} \\ a_{22}^{11} \\ a_{23}^{11} \\ a_{31}^{11} \\ a_{32}^{11} \\ a_{33}^{11} \end{bmatrix} \), the rest of \( W_{ij} \) can be analogized.

(3) The weighted super matrix \( W^\alpha = (T_D^\alpha)^T \times W \)

\[ W^\alpha = \begin{bmatrix} a_{11}^{11}W_{11} & a_{12}^{11}W_{12} & a_{13}^{11}W_{13} \\ a_{21}^{11}W_{12} & a_{22}^{11}W_{12} & a_{23}^{11}W_{13} \\ a_{31}^{11}W_{13} & a_{32}^{11}W_{13} & a_{33}^{11}W_{13} \end{bmatrix} \]

(16)

(4) The weighted super matrix \( W^\alpha \) is stabilized to obtain the weight of influence

The weighted super matrix \( W^\alpha \) is multiplied by itself so that it converges to a stable state.

\[ \lim_{\alpha \to \infty} (w^\alpha)^\beta \]

(17)

4. Result and discussion

According to Table 1, a questionnaire about evaluating interaction of influence indicators for the sustainable development of smart cities is made. We collected the value of the mutual influence of each influencing factor from 7 experts who have rich theoretical knowledge and practical experience in the field of smart cities. After obtaining the initial influence value, the opinions of the experts were integrated, and the results of the integration were returned to the experts for re-evaluation. Repeat this process until the experts make the final consensus.

4.1. Calculate the total influence matrix

According to the collated data, equations (1)-(5) are used to calculate the total influence matrix, and the calculation results are shown in Table 2.

| Factors | \( y_i \) | \( z_i \) | \( (y_i + z_i) \) | \( (y_i - z_i) \) |
|---------|---------|---------|-------------|-------------|
| C1      | 3.0114  | 3.3197  | 6.3311      | -0.3083     |
| C2      | 3.6629  | 2.7594  | 6.4223      | 0.9035      |

4.2. Construct the influential network relationship map

The influence that factors give to other factors is \( y_i \) and the influence that factors receive from other factors is \( z_i \). The value of \( y_i \) and \( z_i \) can be calculated by Equations (6) and (7). According to them, the centrality and causality of dimensions and factors can be calculated respectively. The calculated results are shown in Table 3.

Table 3. Results of interaction among the factors and dimensions.

| Factors | \( y_i \) | \( z_i \) | \( (y_i + z_i) \) | \( (y_i - z_i) \) |
|---------|---------|---------|-------------|-------------|
| C1      | 1.0021  | 0.824   | 1.8261      | 0.1781      |
| C2      | 1.019   | 0.8226  | 1.8416      | 0.1964      |

5
Taking centrality as the horizontal axis and causality as the vertical axis, the influential network relationship maps (INRM) are constructed.

According to the influential network relationship diagram (INRM), we use graph theory to analyze in depth. From the dimensional perspective of the influential network relationship map (Figure 1), the causation degree of smart governance (0.1964) is the highest, and the value of smart people’s livelihood (0.1781) is positive and higher than the negative one of smart city mechanism (-0.3744). Smart governance (D_2) has the highest net impact on the other two dimensions. Therefore, in the process of upgrading and improving from the perspective of dimensions, the order should be: D_2-D_1-D_3. This shows that the operation and management pattern of smart cities has a greater impact on the lives of urban residents and the overall environment of the city. When considering the improvement and enhancement of the sustainable development capabilities of smart cities, we should start with smart governance (D_2). By improving the performance of smart governance (D_2), it will affect and promote performance of other dimensions.

4.3. Calculate the weight of each factor

Equations (8)-(17) are used to calculate the weight of each factor based on the total influence matrix.
obtained from DEMATEL.

Table 4. Weight of each dimension and factor.

| Dimensions | Weight | Factors | Weight |
|------------|--------|---------|--------|
| D1         | 0.2802 | C1      | 0.0772 |
|            |        | C2      | 0.0845 |
|            |        | C3      | 0.1243 |
|            |        | C4      | 0.1002 |
| D2         | 0.2801 | C5      | 0.1130 |
|            |        | C6      | 0.1249 |
|            |        | C7      | 0.0998 |
|            |        | C8      | 0.1127 |
| D3         | 0.4397 | C9      | 0.0927 |
|            |        | C10     | 0.0706 |

According to the results of Table 4, the weight of smart city mechanism (D3) (0.4397) is the largest, and the weight of smart people's livelihood (D1) (0.2802) is close to the weight of smart governance (D2) (0.2801). This shows that smart city mechanism (D3) has the strongest influence on the sustainable development ability of smart cities. In combination with Figure 1, we can see that smart city mechanism (D3) is greatly affected by smart people's livelihood (D1) and smart governance (D2). Therefore, the weight of the smart city mechanism (D1) is the comprehensive result under the influence of the other two dimensions. Combining the results of INRM and Table 4, we conclude that if the information in the smart city is recyclable and safe, and the support of funds, policy and other resource is strong, the construction of medical service, education service and community in the smart city will be more intelligent and excellent. And with the support of a reasonable system, the governance of the smart city, including traffic, environment, urban safety and urban information, will be more efficient.

5. Conclusions and remarks

As a periodical product of urban development, smart city research involves many fields such as information technology, city operation management, resource coordination and so on[12-13]. It is an interdisciplinary research theme. Many scholars have carried out various researches on it from different perspectives. But so far, there have been few studies on the factors affecting the sustainable development of smart cities. This article establishes an evaluation system of factors affecting the sustainable development of smart cities, and uses a mixed decision model to analyze the relationship between these factors according to the influential network relationship map. And by calculating each weight of the influencing factor, we can judge their relative importance. Decision makers can find out the breakthrough point for the improvement of the sustainable development smart cities based on the results. The corresponding policy and economic support can be made according to the weight of influence factors. The conclusions and contributions of the study are summarized as follows:

(1) Established an indicator system of factors affecting the sustainable development of smart cities;

(2) Analyze and calculate the inter-relationships of factors affecting the sustainable development of smart cities and obtain the influence network diagram;

(3) Model calculations to obtain the weights of factors influencing the sustainable development of smart cities.

Furthermore, this article also has some limitations. The initial value of the degree of mutual influence of the influencing factors comes from seven experts in the related fields of smart cities, even if such a number of experts can get a relatively accurate initial value, it can still increase the accuracy of the data by increasing the number of experts. In future research, it is necessary to deeply analyze the reasons for the difference in the degree of mutual influence of different influence factors, so as to more accurately assess and determine the interrelationship between influence factors.
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