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Application And Validity Analysis of IoT In Smart City Based On Entropy Method

Yejin Liu  and Min Ye 

School of Urban Economics and Public Administration, Capital University Of Economics And Business, Beijing City, China

ABSTRACT

This work aims to analyze the application of IoT in the construction of smart city using entropy method, and explore the validity of IoT in smart city based on the input-output perspective. Based on the SC IoT-oriented EIS model, this work can analyze the development status of 31 Chinese smart cities. From 2011–2020, Shanghai(0.1177–0.1607), Beijing(0.1049–0.1132), Guangzhou(0.013–0.1378), Chongqing(0.0708–0.1019) are the four cities with the best status of smart city, the development status of smart city in many central and western regions is still relatively low, such as Taiyuan (0.0151–0.0198), Changchun (0.0202–0.0223), Wuhan(0.0638–0.0331), Xining(0.0102–0.0111), Urumqi(0.0147–0.0167). From the input perspective, the input of capital and labor in IoT has obviously positive correlation with the development of smart city, which have significantly promoted the development of smart city. From the output perspective, IoT has not only promoted the economic development of smart city, but also caused a series of environmental pollution problems. In conclusion, the application of the IoT has promoted the development of smart city, China should further strengthen the investment in IoT technology, so that it can solve the problems of unbalanced development and environmental pollution in urban areas of china

ARTICLE HISTORY

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Introduction

Background and Significance

Authors in (Jararweh, Otoum, and Al Ridhawi 2020) pointed out that Internet of things (IoT) means “Interconnection of all things,” which is the foundation of contemporary information technology. In the meanwhile, it also marks that the development of information technology has entered a new stage. The development of IoT has led to many new connotations. Li et al. (2020) stated that on the one hand, the development of the IoT is based on the Internet. The development of Internet makes the relationship between people and people, people and things, things and things increasingly close, which lays the foundation for the development of the IoT. On the other hand, the IoT has

CONTACT Min Ye  12021010004@cueb.edu.cn  School of Urban Economics and Public Administration, Capital University Of Economics And Business, Beijing City 100070, China

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established an advanced intelligent system by using technologies such as intelligent perception, intelligent identification and big data computing. Patrão, Moura, and de Almeida (2020) combined the perception layer, application layer and planning layer of things, and integrated urban life into a whole through the development of the Internet, making people's life more convenient and faster, laying the foundation for the development of smart cities.

Related Works

Saračević et al. (2019) presented a new method of data hiding using Catalan numbers and Dyck words, provided suggestions for IoT application in business information systems, authentication and distribution of secret cryptographic keys can be used in the construction of smart city to protect the security of private information. Li (2021) analyzed the deep learning (DL) and BDA algorithm, as well as the digital twin technology (DTs) and multi hop transmission technology, which can be used in the construction of smart city to analyze the big data generated by the IoT, to make the smart city governance more efficiently and accurately, and provide the technical basis for the application of IoT in smart city. Wang et al. (2021) studied the literature of IoT from 2000 to 2019, showed that the research of IoT mainly focuses on the security, IoT challenges and privacy, security and algorithm analysis of IoT is the prospect of IoT industry, which provides a direction for the study of the validity of IoT in smart city. Li (2021) considered IoT can be effectively used in smart city to deal with urban development problems, alleviate various ill of modern cities, and make cities healthier and better. Laufs, Borrion, and Bradford (2020) stated the use of the IoT in smart city is conducive to the optimization of urban governance capacity, easing traffic congestion, reducing environmental pollution and other issues. Zong and Lin (2019) divided urban quality into natural quality, transportation and accessibility quality, public service quality, urban vitality quality and urban reputation quality, providing a theoretical basis for the study of smart city.

Research Methods and Innovation

Kopetz and Steiner (2022) considered that IoT makes it possible to connect physical things with the Internet and remotely control physical things through the Internet, creating conditions for the development of smart cities. IoT is not an innovative new technology, but a new management and plan of urban life through RFID, ID and other technologies. Fernandez-Anez, Fernández-Güell and Giffinger (2018) designed a conceptual framework to analyze the plan of smart city construction, providing theoretical support for smart city development from the perspective of urban integrity construction. Maddikunta et al.

(2022) provided application direction of the IoT in smart city, such as IoT security and privacy, IoT mobile crowd sensing, IoT data offloading and caching and IoT data sharing.

On the basis of the above research, this paper contributes to research on the application level of IoT in the construction in different smart cities of China. IFID technology is used in many aspects of smart city construction, such as the second-generation ID card, online payment level, digital economy, etc., which makes people's life more convenient. On the basis of integrated governance theory, this paper establishes an input-output model to analyze the validity of IoT in smart city construction, so as to provide direction for improving the urban planning of smart cities.

The innovation of this paper is that it uses a smart city evaluation model to study the application level of IoT in smart cities, using the entropy method to evaluate the development level of 31 Chinese smart cities. In order to analyze the validity of IoT in smart city construction, this paper establishes an input-output model, evaluates the effect of IoT in smart city construction from the perspective of the input and output factors of IoT, providing theoretical basis for the role of IoT in the construction of smart cities.

Research Method

Establishment of SC Development Level Indexes

Design Principles

Smart city refers to connecting all aspects of urban life through IoT, making it more suitable for people to live in the city through modern technology and improving people's sense of well-being in the city. Building smart city evaluation model based on the application of the IoT can enable people to understand the development level of smart cities, and provide a theoretical basis for more reasonable urban planning.

There is a need for smart city evaluation model to accurately and comprehensively reflect the level of the city's infrastructure, living, enterprise, transportation, logistics, so as to guide the city's development. Therefore, the Smart City (SC) IoT-oriented Evaluation Index System (EIS) model should feature comprehensiveness, reliability, scalability, and guidance, as detailed in [Figure 1](#).

Integrity: The SC IoT-oriented EIS model cannot be concentrated only on one aspect. Especially, the SC construction is an integrated process of Smart Infrastructure (SI), Smart Living (SL), Smart Enterprise (SE), Smart Transport (ST), Smart Logistics (SL). Therefore, the SE oriented EIS is essential to fully reflect inclusive urban development level.

Reliability: The SC IoT-oriented EIS model is a reliable collection of indexes. If EIS cannot collect index data or cannot guarantee data precision,

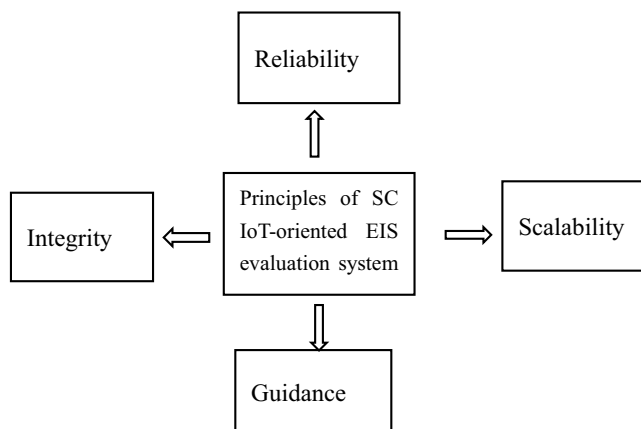


Figure 1. Construction principles of SC IoT-oriented EIS.

the evaluation results based on these indexes will deviate from plan. Therefore, it is necessary to ensure the reliability of indexes to ensure that the established SC IoT-oriented EIS model has a practical reference value to evaluate the SC configuration.

Scalability: Smart city has different requirements at different construction stages and people have varies focus about their lives. Therefore, the SC IoT-oriented EIS model is desirable to maintain pace with time. Especially, the scalability of evaluation indexes in smart city construction should be noticed.

Guidance: The purpose of evaluating the construction level of smart city is to guide the follow-up smart city construction by summarizing recent experiences and shortcomings. Therefore, it is necessary to aim at the index of the SC IoT-oriented EIS model.

Synthesis and Screening of Indexes

Internationally, Smart Community Forum, headquartered in New York, is the first organization to evaluate the widely used of IoT in smart city construction and development (Keshavarzi, Yildirim, and Arefi 2021). In December 2012, the Chinese MHURD issued the MHURD's pilot evaluation indexed for smart city construction. The EIS included four dimensions: smart security, smart infrastructure, smart construction and livability, smart management. The National 13th Five Year Plan has put forward the requirements for accelerating the construction of new urbanization and new SC-oriented EIS. It sets up eight PIs, including three effectiveness indexes (benefiting people's services, precise governance, and ecological livability), four guiding indexes (intelligent facilities, information resources, network security, and reform and innovation) and one index of citizen experience. It emphasizes people-oriented and people's livelihood experience. On May 18, 2019, at the closing session of the third World Intelligence Conference, Wang Guoliang, director of China

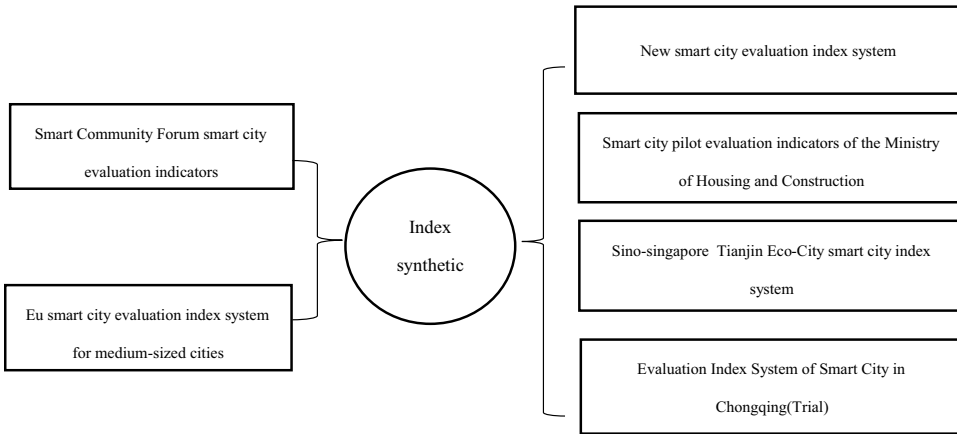


Figure 2. Synthesis of SC IoT-oriented EIS.

Singapore Tianjin Eco-City Management Committee, officially released the China Singapore Tianjin Eco-City Smart City Index System. The system contains six PIs, and 30 SIs are determined according to the requirements of leading demonstration, effect orientation, and highlighting characteristics. In September 2020, Chongqing issues the EIS of Chongqing New SC (Trial version). The EIS includes three PIs: infrastructure construction, intelligent application, and development environment. Next, this section synthesizes the SC IoT-oriented EIS model established in such MEDCs and European nations and United States the Chinese SC IoT-oriented EIS model, as illustrated in Figure 2.

Establishment of SC IoT-Oriented EIS

Subsequently, this section constructs the SC IoT-oriented EIS model, according to the principles of integrity, reliability, scalability, and guidance. Table 1 tabulates the constructed SC-oriented EIS, including 5 PIs and 25 SIs. Specifically, the five PIs are Smart Infrastructure, Smart Living, Smart Enterprise, Smart Transportation, and Smart Logistics.

Analysis and Construction of SC IoT-Oriented EIS Model Based on Entropy Method

Entropy Analysis

Entropy method is a mathematical calculation method, which can be used to calculate the degree of dispersion between indicators. The greater the dispersion between indicators, the greater the impact of the indicators on the results. The definition of entropy originated from thermodynamics and was first used to measure the uncertainty of a system. Compared with principal component analysis, entropy method can better measure the weight of indicators. In this

Table 1. SC IoT-oriented EIS model.

Primary index	Secondary index
Smart Infrastructure	Total urban water supply X_1
	Total urban power supply X_2
	Length of drainage pipe X_3
	Coal gas and natural gas supply X_4
Smart Living	Number of people using second generation ID cards X_5
	Number of bank outlets X_6
	Internet broadband access users X_7
	Mobile phone penetration X_8
	Number of computers used per 100 people X_9
Smart Enterprises	Modern hospital X_{10}
	Enterprise digital economy index X_{11}
	Enterprise information development index X_{12}
	Telecommunication business income X_{13}
Smart Transportation	Online mobile payment level X_{14}
	Proportion of enterprises with electronic trading activities X_{15}
	Highway mileage X_{16}
	Car ownership X_{17}
	High speed railway passenger transport turnover X_{18}
Smart Logistics	Civil aviation passenger volume X_{19}
	Urban Road area X_{20}
	Number of post offices X_{21}
	Postal business income X_{22}
	Express business income X_{23}
	Number of express outlets X_{24}
	Express volume X_{25}

Table 2. Regression effect analysis of capital input factors.

Smart city				
Regression Coefficient	Number of post offices	Number of express outlets	Internet broadband access users	Number of utility model patent applications
Total	424.2343*** (8.5133)	48.3599*** (2.8500)	40.0773** (2.1062)	538.5976*** (10.7679)
Year fixation (√) Individual fixation (×)	0.1646*** (6.8473)	0.1555*** (16.1160)	0.0617*** (13.6757)	0.0062 (0.7128)
Year fixation (×) Individual fixation (√)	0.1490*** (7.5499)	0.1368*** (17.6066)	0.0678*** (17.2942)	0.0236*** (3.6336)
Year fixation (√) Individual fixation (√)	0.0011 (0.0566)	0.0902*** (8.2907)	0.0166*** (3.9686)	0.0038 (0.8512)
_cons	169.0525*** (23.4143)	2.8632 (0.3320)	17.7673 (0.9300)	141.4562*** (6.6567)
N	300	300	300	300
r2	0.4650	0.9297	0.9380	0.9805
F	75.7693	320.6743	286.4926	379.1423

t statistics in parentheses * $p < .10$, ** $p < .05$, *** $p < .01$

paper, the use of entropy method can better measure the use level of the IoT in cities, making the research results of this paper more accurate.

Construction of SC IoT-Oriented EIS Model

The SC IoT-oriented EIS model is realized according to the entropy method. When using entropy method to analyze, firstly standardize the

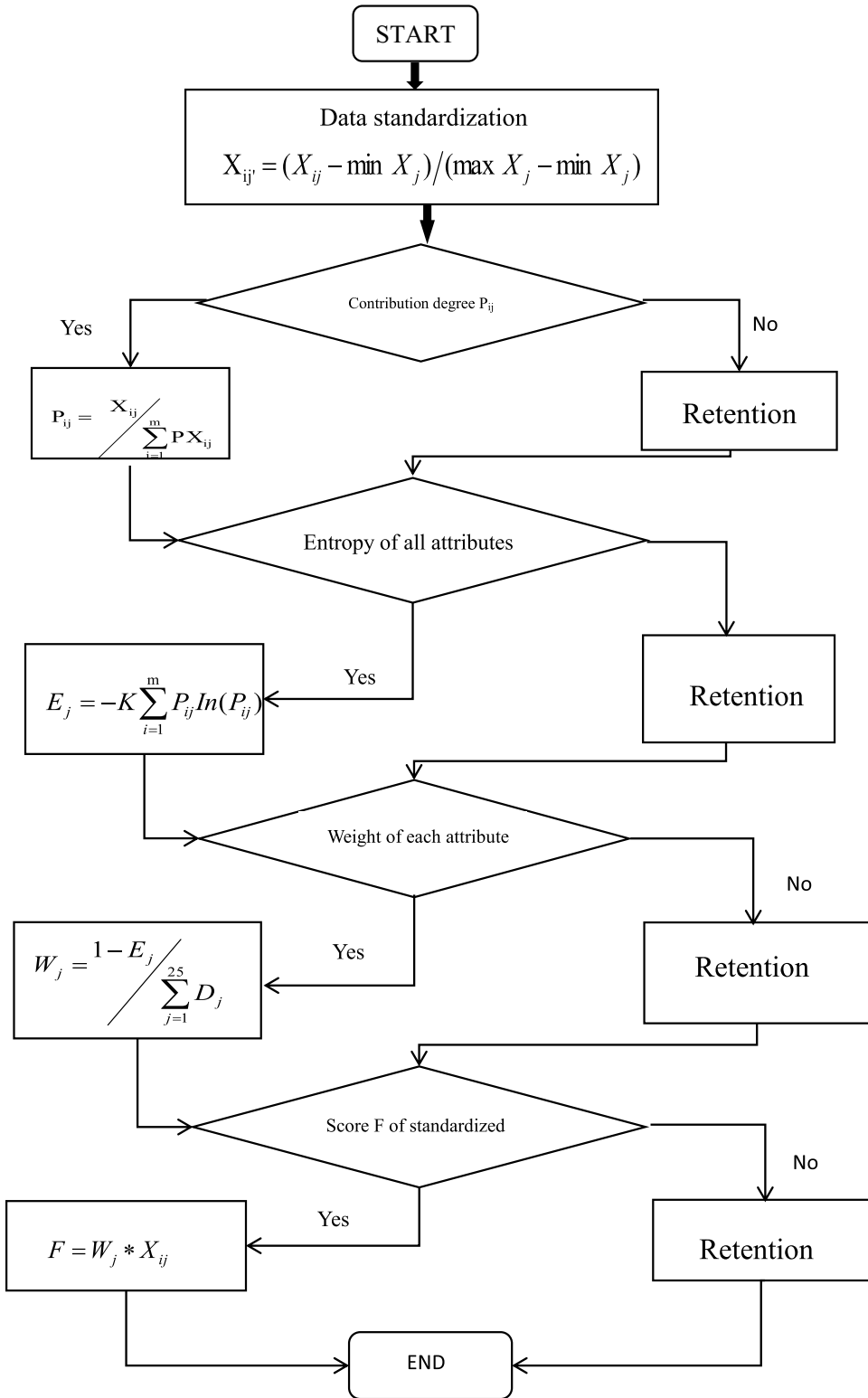


Figure 3. Entropy flowchart.

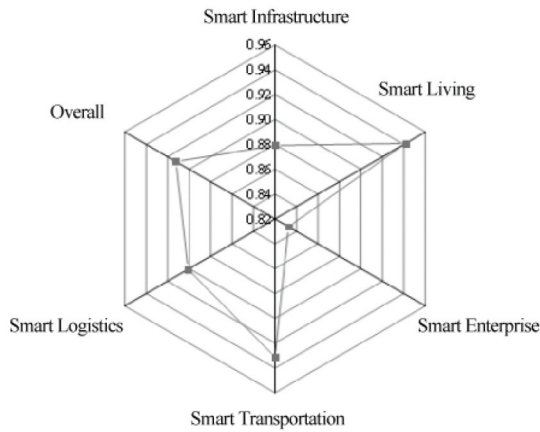


Figure 4. Reliability test results of SC IoT-oriented EIS.

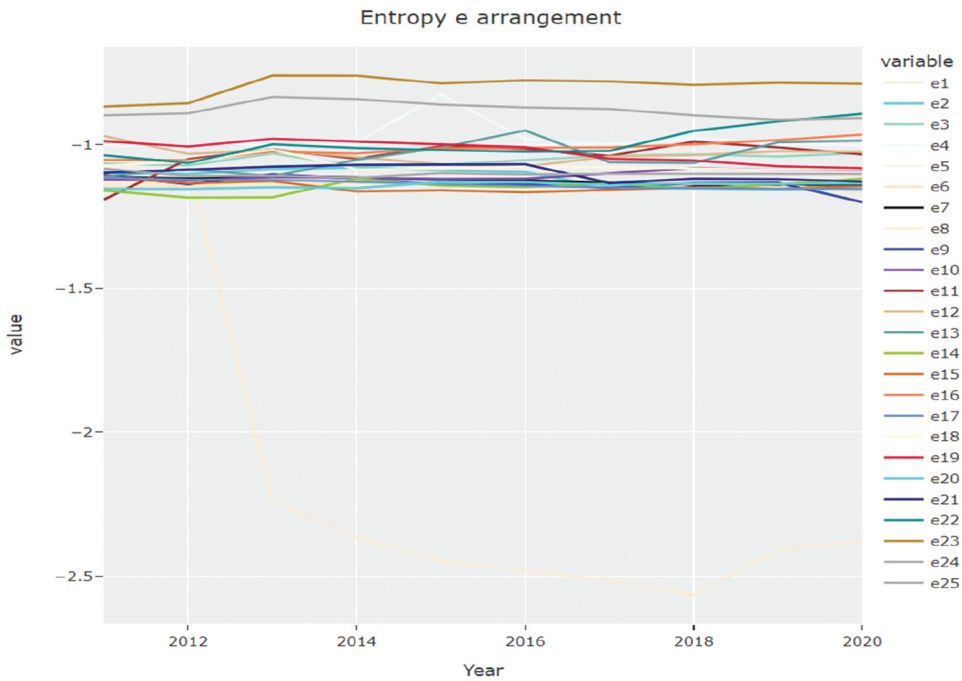


Figure 5. Entropy e arrangement.

original data, then calculate the original matrix, contribution, entropy and weight respectively, and finally comprehensively evaluate the development of smart city, so as to determine the smart city evaluation model. When evaluating the smart city model with entropy method, the specific calculation steps of entropy method are as follows in [Figure 3](#).

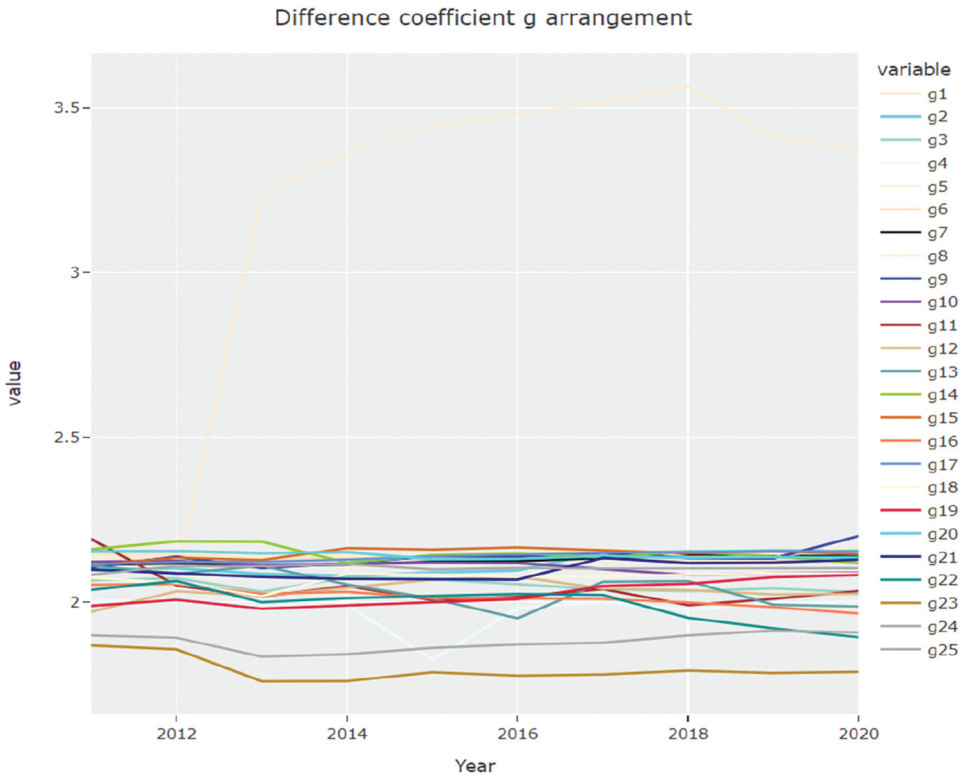


Figure 6. Difference coefficient g arrangement.

Impact of IoT on the Society

Wang, Zhou, and Wang (2020) stated the widespread use of IoT, like “Butterfly Effect,” triggered the third scientific and technological revolution, which has had a profound impact on all aspects of social life. Wang and Zhou (2023) considered as far as cities are concerned, the wide application of IoT has made people’s living more and more convenient. There is a famous European saying in the Middle Ages: “The air in cities makes people free.” Cities make life better, making people more and more intelligent, and further promoting the popularization and application of IoT.

This paper aims to analyze the application of IoT in cities. The application of IoT in smart cities is divided into five aspects: smart infrastructure, smart living, smart enterprise, smart transportation and smart logistics. Through the analysis of 31 major cities in China, the use status of IoT in urban construction is clarified. At the same time, the validity of IoT in smart cities is studied by input-output method, deeply analyzing the effect of IoT in smart cities, providing a theoretical basis for modern urban governance.

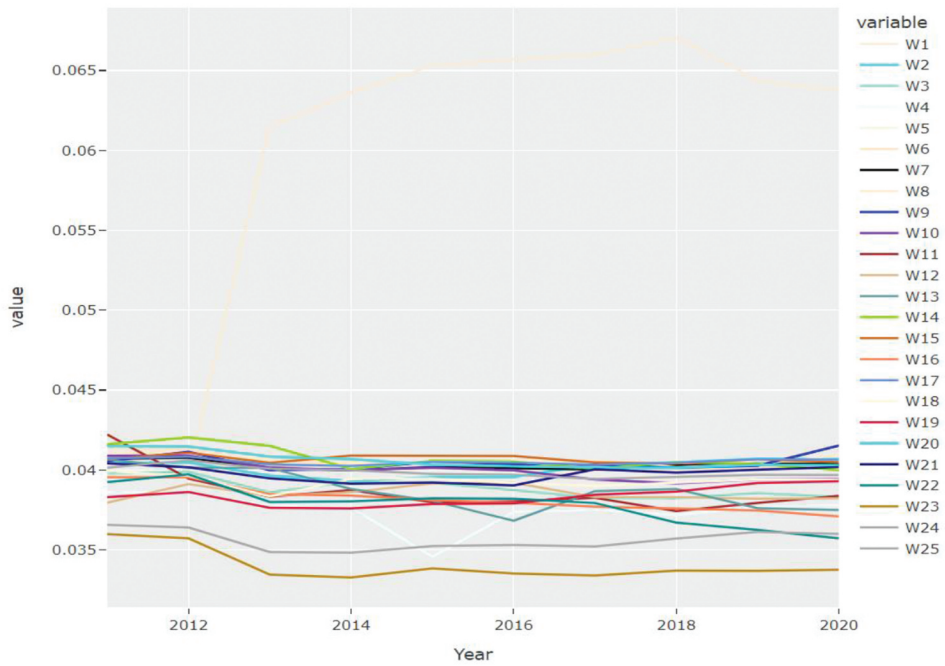


Figure 7. Weight W arrangement.

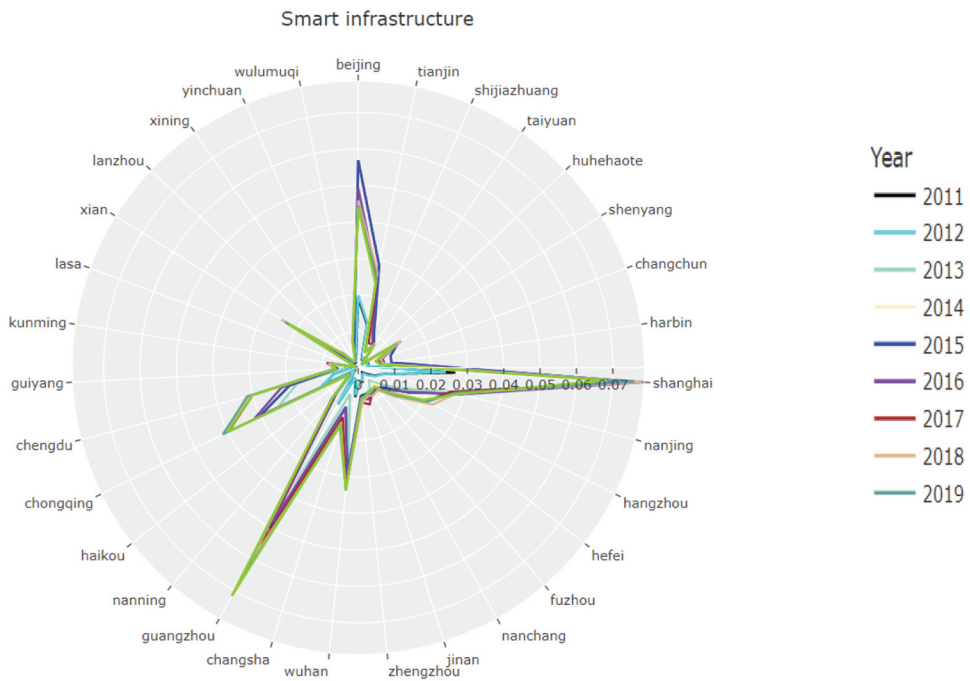


Figure 8. Smart infrastructure level from 2011–2020 in 31 cities.

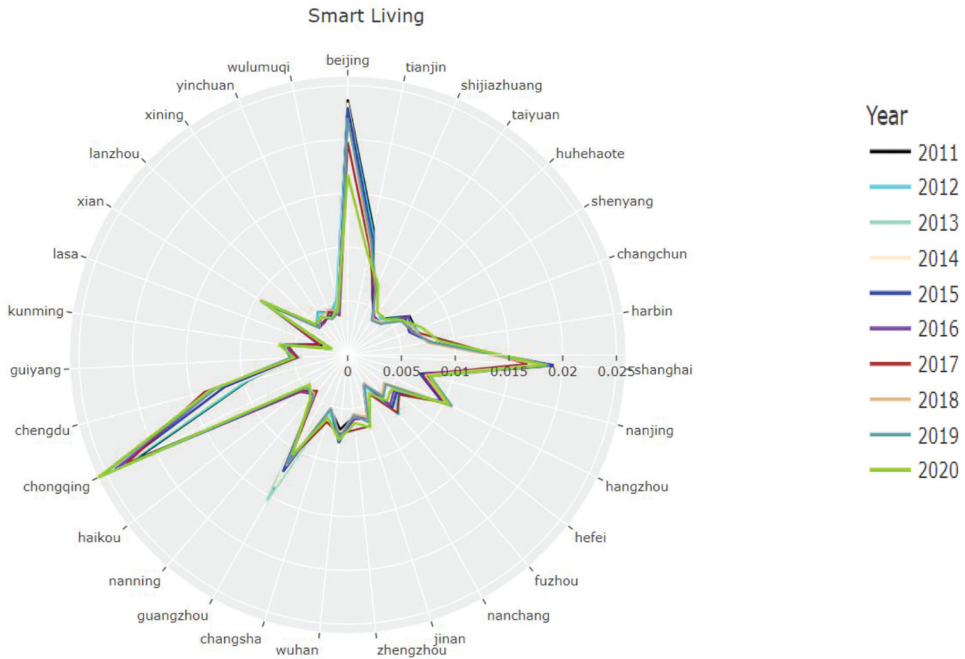


Figure 9. Smart living level from 2011–2020 in 31 cities.

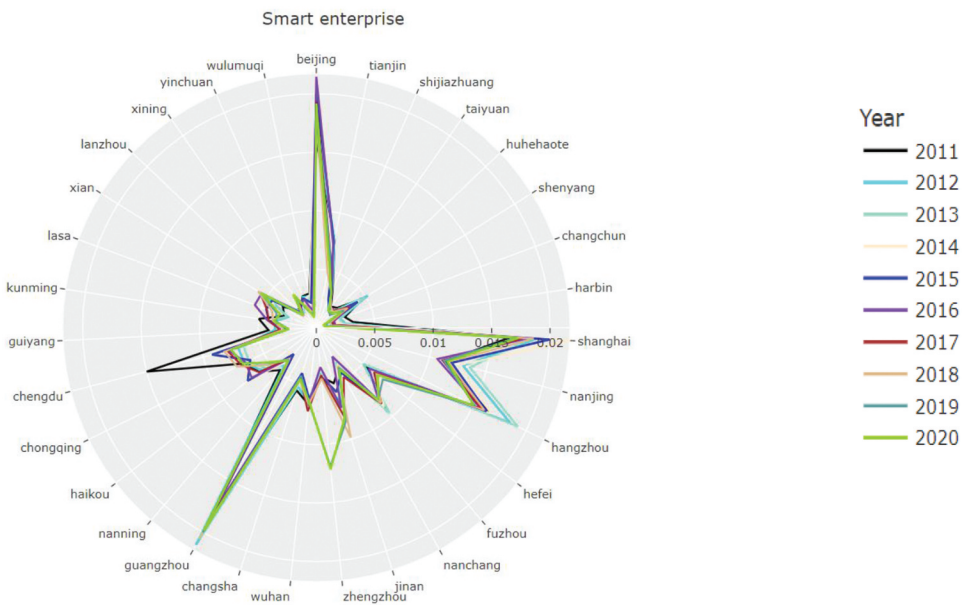


Figure 10. Smart enterprise level from 2011–2020 in 31 cities.

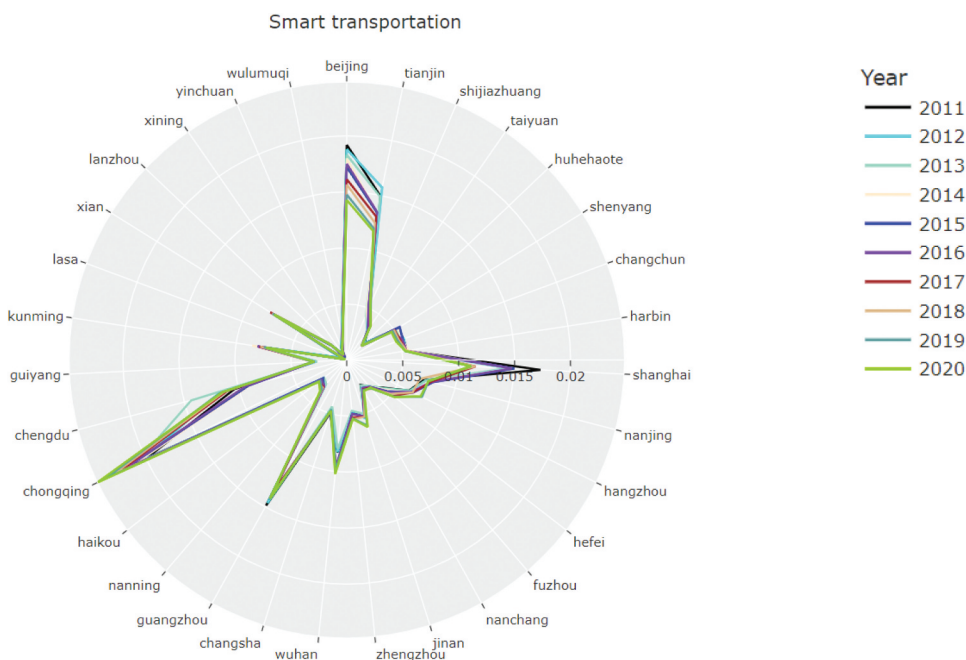


Figure 11. Smart transportation level from 2011–2020 in 31 cities.

Results and Discussion

Reliability Test of SC- EIS

The reliability test ensures the internal stability and reliability of the index. Significantly, this section employs Cronbach's alpha coefficient (ranges between 0–1) to test the reliability of the proposed SC-oriented EIS. If Cronbach's alpha coefficient is calculated to be more than 0.9, the EIS has high reliability. If it is below 0.7, the reliability level is low, and the EIS has noticeable defects. If it is between 0.8–0.9, the reliability is within the allowable range; if it is between 0.7–0.8, there are some loopholes in the EIS.

The proposed SC IoT-oriented EIS encompasses five dimensions: Smart infrastructure, Smart Living, Smart enterprise, Smart transportation, and Smart logistics. Based on Cronbach's alpha coefficient, the result is illustrated in [Figure 4](#).

[Figure 5](#) corroborates that the Cronbach's alpha coefficient of the proposed SC IoT-oriented EIS' each PI dimension is between 0.8–1, indicating that the system reliability is within the allowable range. Remarkably, the Cronbach's alpha coefficients of Smart Infrastructure, Smart Living, Smart Enterprise,

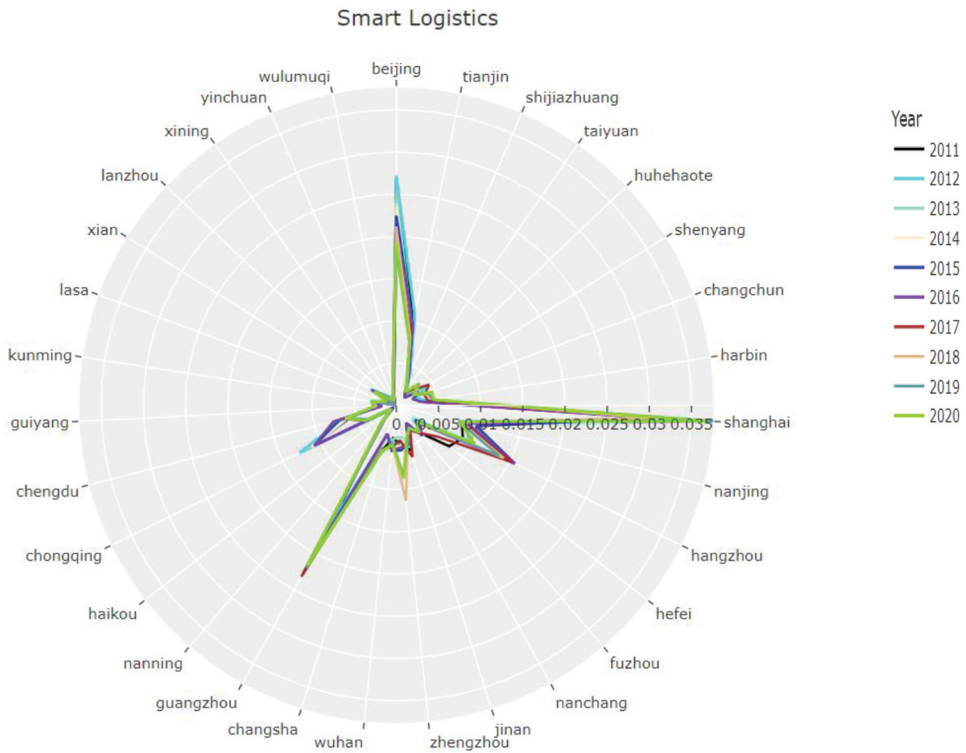


Figure 12. Smart logistics level from 2011–2020 in 31 cities.

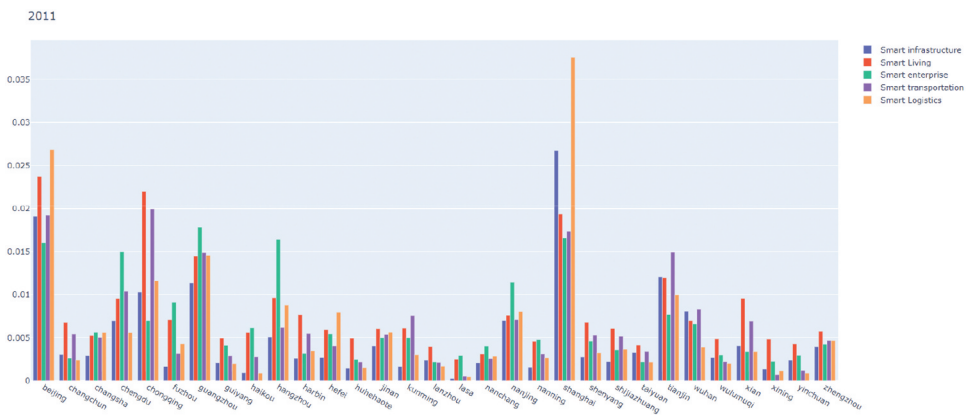


Figure 13. Development level of first-class indicators of smart city in 2011.

Smart Transportation, and Smart Logistics are 0.8997, 0.9426, 0.8198, 0.9312, and 0.9118, respectively, all above 0.9. The results indicate that the reliability is high, and the overall Cronbach’s alpha coefficient is 0.90102, meaning that the overall system reliability is also high.

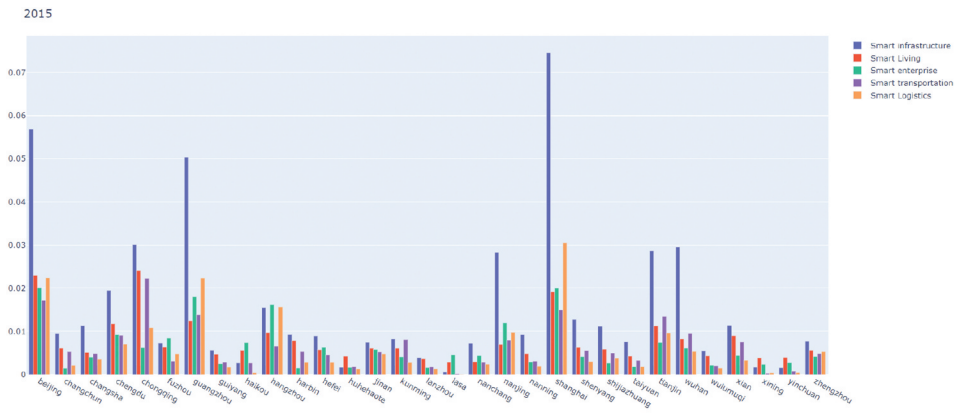


Figure 14. Development level of first-class indicators of smart city in 2015.

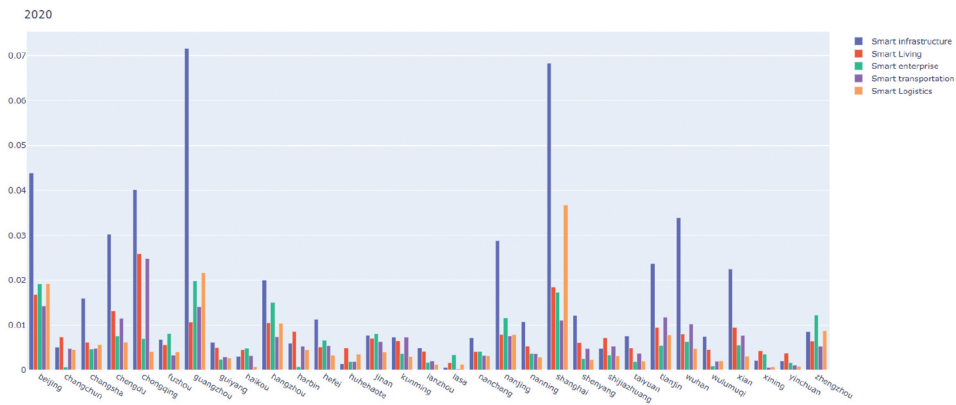


Figure 15. Development level of first-class indicators of smart city in 2020.

Analysis on the Use of IoT of 31 Smart Cities in China

This paper analyzes the use of IoT in 31 super large and large cities in China, analyzes the development status of smart cities in China by using 25 secondary indicators and 5 primary indicators, and defines the role of IoT in the construction of smart cities in China, so as to further promote the development of cities to be more intelligent, urban life to be more convenient and urban management to be more effective.

Development Status of Smart Cities in China

In order to study the role of IoT in the construction of smart cities, this paper uses the entropy method to evaluate the application of IoT in the construction of smart cities, and uses the quantitative analysis method to evaluate the application level of IoT in 31 cities, so as to measure the development situation of smart cities.

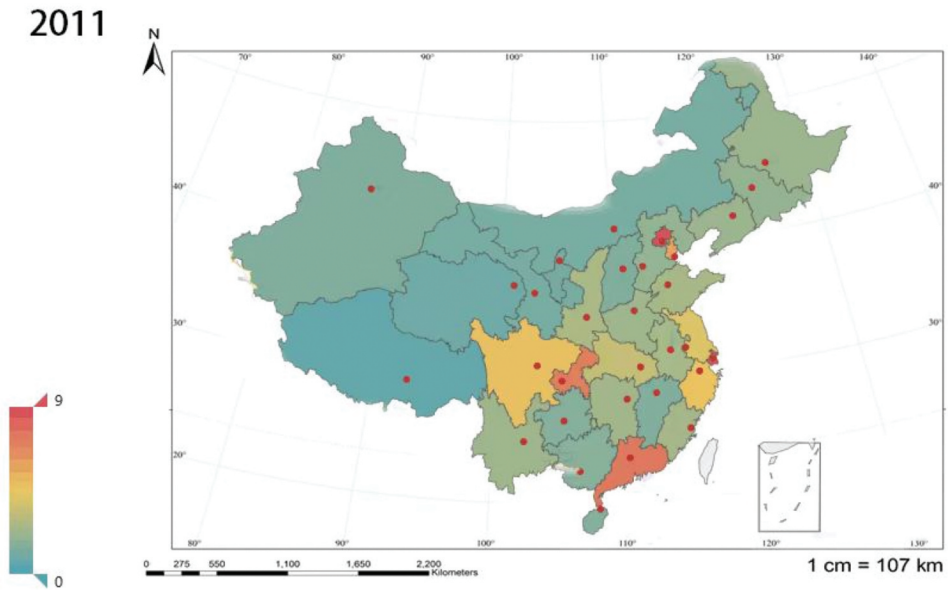


Figure 16. Smart city level in 2011.

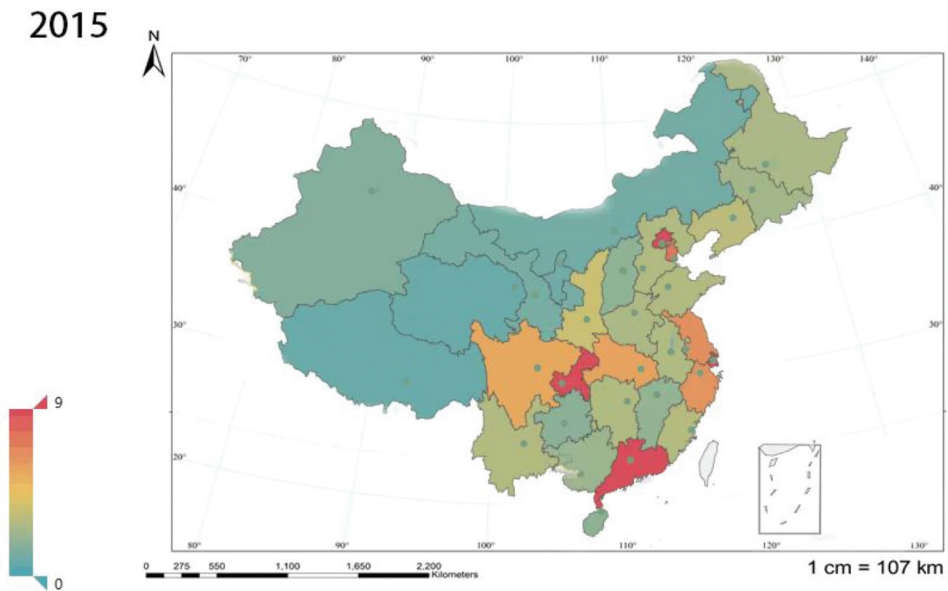


Figure 17. Smart city level in 2015.

Through the analysis of entropy method in different cities, it can be seen in [Figure 5](#) that from 2011 to 2020, the change trend of entropy method is small and in a relatively stable state.

By using the entropy method to analyze the difference coefficient of different cities from 2011 to 2020, we can find that the change direction of difference

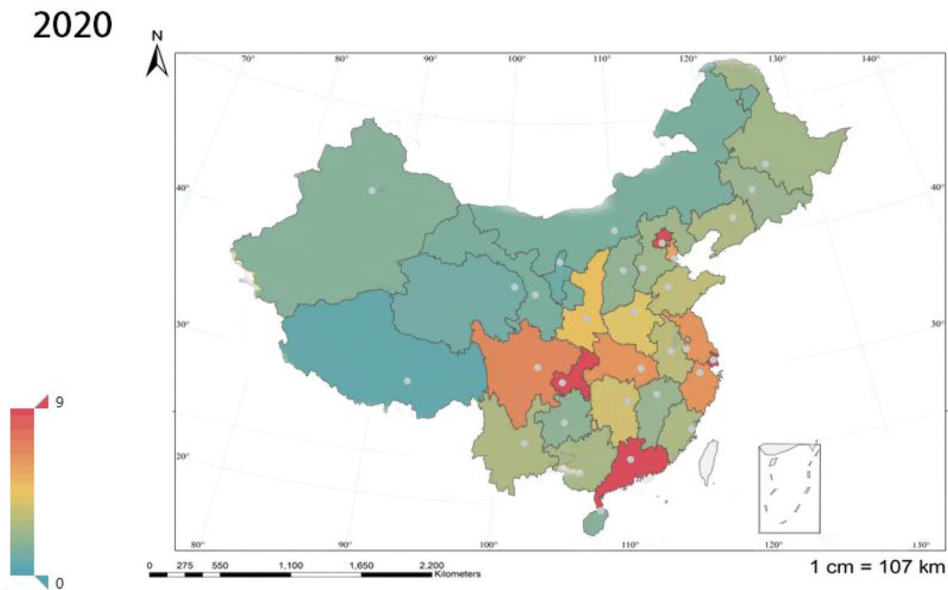


Figure 18. Smart city level in 2020.

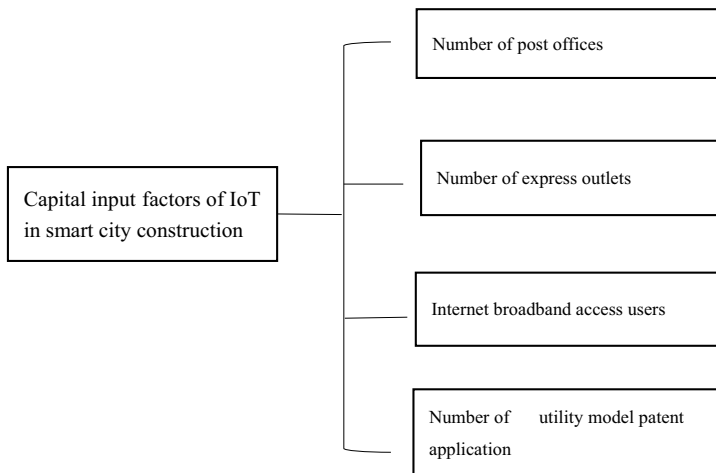


Figure 19. Capital input factors of IoT in smart city construction.

coefficient g is opposite to the direction of entropy e , showing a negative correlation. As is illustrated in Figure 6, the larger the value of entropy e , the smaller the difference coefficient g ; The smaller the entropy e , the larger the difference coefficient g

From the weights of indicators of different cities from 2011 to 2020, we can see in Figure 7 that the relationship between indicator weights and time is not significant. Among them, the highest weight value is the express business volume and telecommunications business volume, indicating that the use of

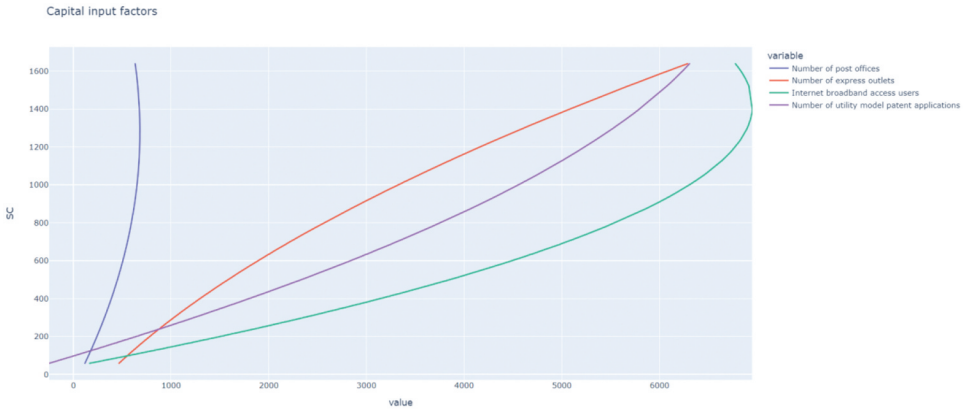


Figure 20. Correlation analysis of capital input factors of IoT in smart city construction.

Capital input factors of IoT

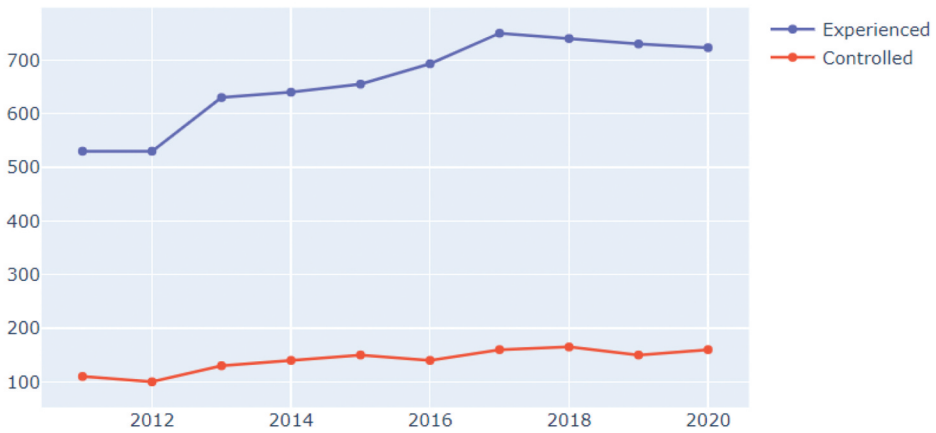


Figure 21. Comparative effect analysis of smart city capital input factors of IoT in different regions.

the IoT plays a very significant role in urban logistics and mobile communication. In 2015, the total supply of natural gas, water and electricity in 31 cities began to decline after reaching the maximum, indicating that the use of IoT has greatly reduced the waste of energy and realized the construction of a resource-saving society.

The IoT has been widely used in urban infrastructure, laying the foundation for the infrastructure construction of smart cities (Aleksic 2019). As can be seen from the above Figure 8, the level of smart infrastructure construction in mega cities is very high. Among them, Shanghai has the highest level of smart infrastructure, followed by Guangzhou, Beijing is the third, followed by Chongqing and Chengdu. The construction of smart infrastructure makes urban life more convenient and smarter.

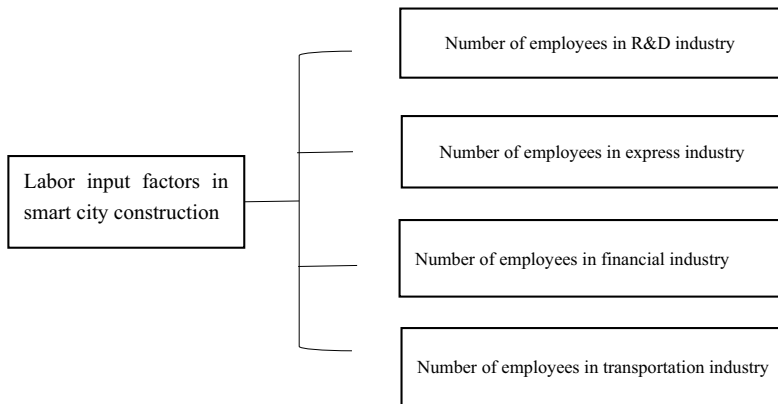


Figure 22. Labor I input factors of IoT in smart city construction.

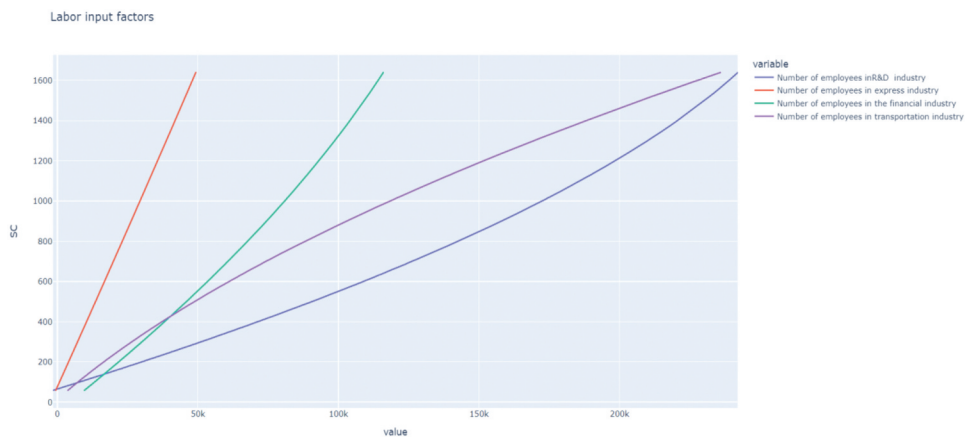


Figure 23. Correlation analysis of labor input factors of IoT in smart city construction.

By analyzing the smart living indicators of 31 cities in [Figure 9](#), we can find that from 2011 to 2020, the smart city living standard in Chongqing is the highest, reaching 0.025, the smart life level in Beijing is the second, the average value between 2011 and 2020 was 0.023, and the smart life development level in Shanghai is the third, reaching 0.022. This shows that the IoT technology is most widely used in Chongqing, providing more convenience for urban life.

Through the application level of IoT in enterprises of 31 cities in [Figure 10](#), we can find that from 2011 to 2020, the level of smart enterprise has been greatly improved. Among them, the smart level of Guangzhou enterprises is the highest, with an average of 0.0231, which shows that IoT in Guangzhou occupies a great position in the process of enterprises production, and the digital level of enterprises is very high. The development level of smart enterprise in Beijing and Shanghai is also very high, which indicates that the

Labor input factors of IoT

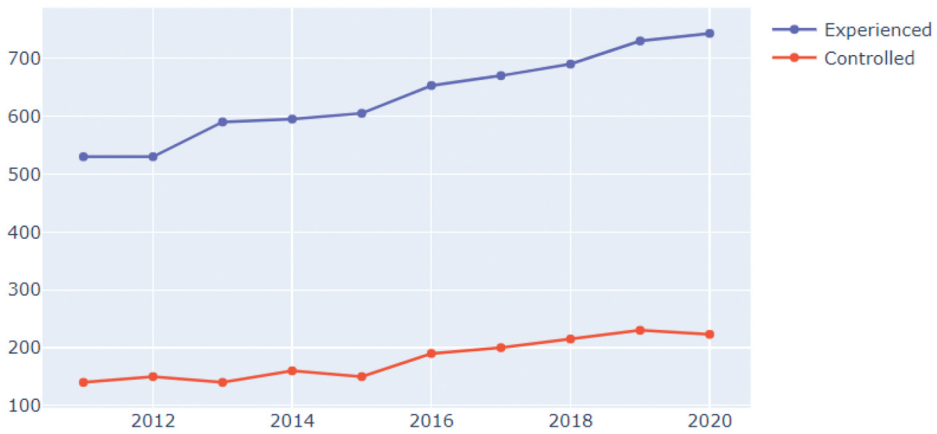


Figure 24. Comparative effect analysis of smart city labor input factors of IoT in different regions.

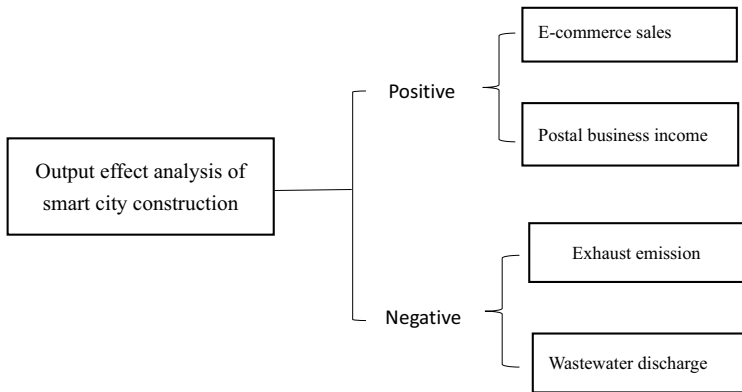


Figure 25. Output effect analysis of smart city construction model.

IoT is widely used in enterprises production in super large cities such as Beijing and Shanghai, and is a major force to promote economic development.

The application of the IoT in smart cities has greatly improved people’s lives and made their travel more convenient (Zantalis et al. 2019). As is shown in Figure 11, the widely used of IoT in highway has reduced people’s travel cost and improved travel speed. The IoT is widely used in the global positioning system, so that car owners can travel more conveniently. The application of IoT in high-speed railway makes population migration between cities more convenient and promotes the development of urban belt. The application of IoT in urban roads and traffic, such as ETC, all-in-one bus card, road camera etc., makes urban life more intelligent and provides more convenience for people to travel. Through the study of 31 cities from 2011 to 2020, we can find that Chongqing has the highest level of smart transportation development,

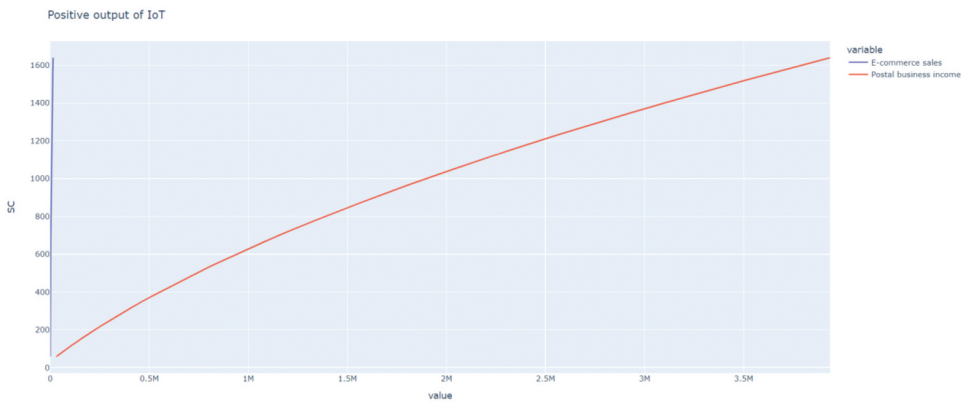


Figure 26. Correlation analysis of positive output of IoT in smart city construction.

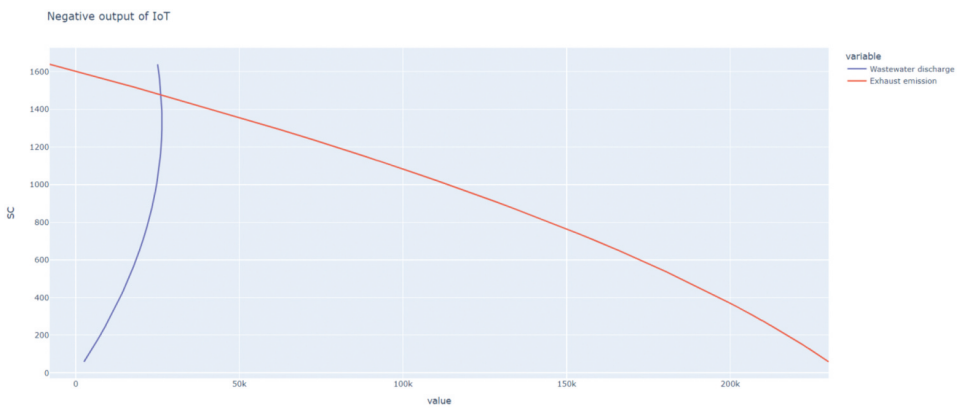


Figure 27. Correlation analysis of negative output of IoT in smart city construction.

reaching 0.0234, followed by Beijing, Guangzhou and Shanghai, and is also in the leading position in China. Through the research on intelligent transportation, it shows that the smart transportation level of hot large cities is at the leading level. On the other hand, it also provides a new idea for the solution of urbanization problems in China.

As is shown in Figure 12, IoT is widely used in the field of logistics, including a series of logistics processes, such as logistics QR code, visual logistics, automatic unmanned transportation system, logistics robot, rookie post station, express self delivery cabinet, etc. The application of IoT has greatly improved the speed and time of cargo transportation, and changed people's way of living. Through the study of 31 cities from 2011 to 2020, we found that Shanghai has the highest level of smart logistics, with an average value of 0.0347. Beijing also has a high level of smart logistics, with an average value of 0.0228. Guangzhou ranks third in the level of smart logistics. The application of IoT in the field of logistics makes the transportation of goods

between cities more and more convenient and faster, and promotes the economic development.

From [Figure 13](#), we can see that in 2011, the top three cities in terms of Smart Infrastructure development were Shanghai(0.02675), Beijing(0.01911) and Tianjin(0.01208), and the three worst developed cities were Xining (0.00136), Haikou(0.00092) and Lhasa(0.00027).The top three cities with Smart Living standards are Shanghai(0.02370), Shijiazhuang(0.02199) and Hangzhou(0.01938), and the three cities with the worst development level are Hohhot(0.00394), Changchun(0.00308) and Kunming(0.00248). The top three cities in the level of Smart Enterprises are Guangzhou(0.01781), Shanghai(0.01659) and Hangzhou(0.01641), and the three cities with the worst development level are Xining(0.00225), Taiyuan(0.00219) and Lanzhou(0.00217). The top three cities in Smart Transportation level are Chongqing(0.01997), Beijing(0.01921)and Shanghai(0.01733), and the three cities with the worst development level are Yinchuan(0.00117), Xining (0.00069) and Lhasa(0.00051). The top three cities in the level of Smart Logistics are Shanghai(0.03760), Beijing(0.02686) and Guangzhou(0.01457), and the three worst developed cities are Yinchuan(0.00088), Haikou(0.00084) and Lhasa(0.00045).

From [Figure 14](#), we can see the situation of smart city development in 2015, the cities with Smart Infrastructure well-development are Shanghai(0.07457), Beijing (0.05691) and Guangzhou (0.05037), and the cities with poor development are Hohhot (0.00168), Yinchuan(0.00156)and Lhasa(0.00058). The three cities with the best development Smart Living standards are Chongqing (0.02408), Beijing(0.02296) and Shanghai (0.01918), and the three cities with the worst development are Lanzhou(0.00364), Nanchang(0.00301) and Lhasa (0.00291). The three cities with the best development level of Smart Enterprises are Beijing(0.02007), Shanghai(0.01999) and Guangzhou (0.01801), and the three cities with the worst development level are Lanzhou (0.001572),Harbin(0.00147) and Changchun (0.00144). The three cities with the best development level of Smart Transportation are Chongqing(0.02224), Beijing(0.01723) and Shanghai(0.01502), and the three cities with the worst development level are Yinchuan(0.00083), Xining(0.00025) and Lhasa (0.00018). The cities with the best development level of Smart Logistics are Shanghai(0.03052), Beijing(0.02245) and Guangzhou(0.02237), and the three cities with the worst development level are Haikou(0.00039), Xining(0.00037) and Lhasa(0.00037).

According to the [Figure 15](#), we can see that in 2020, the top cities in the development of Smart Infrastructure are Guangzhou(0.07159), Shanghai (0.06832) and Beijing(0.04385), and the three cities with the lowest development level are Yinchuan(0.00197), Hohhot(0.00136) and Lhasa(0.00056). The cities with the highest Smart Living standard are Chongqing(0.02589), Shanghai (0.01851) and Beijing (0.01674), and the cities with the worst development level

are Nanchang(0.00409), Yinchuan(0.00376) and Lhasa(0.00158). The cities with the highest development level of Smart Enterprises are Guangzhou(0.01977), Beijing(0.01916) and Shanghai(0.01730), and the cities with the lowest development level are Urumqi(0.00091), Harbin(0.00072) and Changchun(0.00068). The cities with the best development level of Smart Transportation are Chongqing (0.02482), Beijing(0.01428) and Guangzhou(0.01413), and the cities with the lowest development level are Yinchuan(0.00106), Xining(0.00057) and Lhasa (0.00015). The top three cities in the development level of Smart Logistics are Shanghai(0.03675), Guangzhou(0.02167) and Beijing(0.01919), and the last three cities in the development level are Yinchuan(0.00082), Haikou(0.00075) and Xining(0.00074).

Based on the application level of the IoT in the construction of smart cities in 31 cities from 2011 to 2020, as is shown in [Figure 16](#), we can find that in 2011, the development level of smart cities in Beijing(0.1049), Chongqing (0.0708), Chengdu(0.0474), Shanghai(0.1176) and Guangzhou(0.0731) Tianjin(0.0566) are the highest, followed by Hangzhou(0.0460), Nanjing (0.0411), Wuhan(0.0338), Xian(0.0272), Jinan(0.0260), Zhengzhou (0.0233), the cities with backward development level are Lhasa (0.0066), Xining(0.0102), Yinchuan(0.0116), Lanzhou(0.0122) and Huhhot(0.0125). Regional differences in the development level of smart cities are also quite obvious, and there is a big gap in the development of the Eastern, Central and Western regions.

By analyzing the development of smart cities in 2015 in [Figure 17](#), we can see that the smart development level of cities in China has been greatly improved. The smart level of cities in Beijing(0.1396), Shanghai(0.1592), Guangzhou (0.1170), Chongqing(0.0936) and Tianjin(0.0703) are still at a relatively high level. The smart level of cities in Wuhan(0.0588), Hangzhou(0.0648), Nanjing (0.0636), Chengdu(0.05655) have been significantly improved. The development level of cities such as Xi'an (0.0356), Xining(0.0085), Shijiazhuang(0.0283) and Shenyang(0.0319) has also made great progress. At the same time, compared with 2011, the development level of smart cities in China has also been greatly increased.

As is shown in [Figure 18](#), in 2020, the development level of China's smart cities has been further improved. The development level of smart cities in Beijing (0.1132), Shanghai(0.1519), Guangzhou(0.1378), Chongqing(0.1019) and Chengdu(0.0685) have been further deepened. At the same time, many development points have emerged. Xi'an(0.0481), Wuhan(0.0631), Nanjing(0.0635), Hangzhou(0.0632) and other cities have further improved their smart cities development level and become new force for urban development. The urbanization development level of the central region has been greatly improved. Compared with 2011, the development level of Taiyuan(0.0198), Shijiazhuang(0.0235), Zhengzhou(0.0411), Wuhan(0.0631), Changsha(0.0371) and other cities have made great progress, which have promoted the regional balance. The

development level of smart cities in the western region have also been greatly improved. The development level of smart cities such as Urumqi(0.0167), Lhasa (0.0068), Xining(0.0111), Nanning(0.0262) and Lanzhou(0.0138) have made great progress, promoting the balanced development of the region.

Validity Analysis of Smart City Development

Analysis on Capital Input Factors of IoT in Smart City Construction

Smart cities based on IoT information collecting and analyzing, such as communication technologies, remote sensing and insitu sensors (Wolf et al. 2022). The goals of smart cities require preserving human and social capital as well as enhancing the quality of lives (Pira). The development of smart city requires a lot of resources from all aspects of society. The application of IoT in smart city not only promotes economic development, but also drives social micro changes, thus promoting the development process of the whole society (Bibri and Krogstie 2017). A novel block encryption method was provided to ensure data security, promoting the healthy development of smart cities (Saračević, Sharma, and Ahmad 2022). The input in smart city construction needs to be considered from several aspects: human input and capital input. In order to study the relationship between smart city capital input factors and smart city construction, this paper analyzes the capital input factors of smart city construction from four aspects. The construction of post offices is the key link of smart log

istics. The application of the IoT in postal industry has improved the development level of the smart logistics industry. Therefore, the number of post offices is taken as a major indicator to evaluate the capital input factors of smart city. The development of express outlets is the key link of logistics transportation. The application of IoT in express outlets is very common, such as express order number bar code, express visual logistics, express information real-time tracking, unmanned express machine, etc. These inputs not only make the express industry more and more convenient, but also promote the development process of smart city. The number of Internet broadband access users is an important indicator to measure the development of smart city. The access of Internet broadband requires a lot of capital investment, enables people to access the Internet and make life faster, which is the basis for the development of smart city. Therefore, the number of broadband access users in the city is taken as an indicator to measure the input in smart city, so as to study the impact of smart city capital input. The IoT is increasingly popular in smart city construction, which is inseparable from people's R&D (Research and Development) and patents input in the IoT. Patents promotes the progress of science and technology, make researchers have more enthusiasm for research, promoting the development of science and technology and the improvement of smart city level. Therefore, the

number of utility model patent application is also can be used as an indicator of smart city capital input, so as to measure the impact of scientific and technological capital input on smart city construction, providing a basis for further improving the level of smart city development, as is shown in [Figure 19](#).

From the above [Table 2](#), it can be seen that the construction of post offices, express service outlets, Internet broadband access and utility patent applications have significantly promoted the construction of smart cities. It shows that the improvement of urban smart level depends on social investment, which provides a theoretical basis for the improvement of urban smart development level.

The [Figure 20](#) shows the correlation between smart city construction and various indicators. There is a strong correlation between the number of post offices and smart cities, the number of express outlets is also has strong correlation with smart cities, indicating that the construction of post offices and express outlets can significantly promote the development of smart logistics, further improving the construction level of smart cities. The number of applications for utility patents also has a positive impact on the construction of smart cities, indicating that the application for utility model patent applications improves the city's R&D capacity and promotes the development of smart cities. The state's investment in Internet construction has increased the number of urban Internet users, enabled people to learn more information, and promoted the construction of smart cities.

In order to study the differences in the development of smart cities in different regions, DID model is used to compare the 15 cities with high development of smart cities as Experienced Group, such as Beijing, Tianjin and Shanghai, etc., the regions with low development of 15 smart cities as Controlled Group, such as Lhasa, Xining and Lanzhou, etc. As in shown in [Figure 21](#), we find that the development level of smart cities in East and West has been greatly improved, but the growth rate of smart cities in the eastern region is higher than that in the central and western regions, as time went on, the gap is stronger.

Analysis of Labor Input Factors in Smart City Construction

The development of smart city depends on both material capital investment and human capital investment (Tura and Ojanen 2022). In order to study the relationship between human capital investment and smart city, this paper studies the relationship between human capital investment and smart city in each city. Labor input in the IoT industry has promoted the rapid development of smart city. The increase in the employed population in R&D industry has promoted the innovation of IoT technology and laid a technical foundation for the development of smart city. The labor input of the express industry has

provided impetus for the application of IoT technology in smart city, improved the level of smart logistics, and promoted the improvement of the level of smart city. The investment in the number of employees in the financial industry has promoted the country's financial level and provided an economic foundation for the development of smart city. Transportation industry is the hub of urban development and the key to promote the development of smart city. The investment of the IoT in transportation has promoted the modernization of the transportation industry, and the input of transportation practitioners has promoted the prosperity of the transportation industry. Therefore, this paper brings these factors into the development category of smart city, and studies the impact of labor input on the development of smart city, as is shown in [Figure 22](#).

The [Figure 23](#) describes the correlation between smart city construction and labor input. We can see from the picture that the number of express employees is most closely related to the construction of smart city, which indicates that the number of express employees increasing has promoted the development of smart logistics and the development level of smart city. The number of employees in financial industry also has a strong correlation with the development of smart cities, indicating that the increase in the number of employees in financial industry has improved the development level of the city's smart economy and promoted smart cities properties. The increase in the number of employees in R&D industry has also promoted the grow of smart cities, which shows that smart cities also depend on the improvement of employees in the technology industry. The increase in scientific and technological investment has promoted the blooming and popularization of IoT technology, and has become an important force in promoting the flourishing of smart city.

Through the comparative analysis of different cities in [Figure 24](#), we find that labor input in IoT related industries has a positive role in promoting the development of smart city. The development trend of smart cities in the eastern, central and western regions has improved, indicating that the labor input has promoted the development of smart cities from 2011 to 2020. However, there is still a big gap in the development of smart cities in the east, central and western regions. The application of the IoT has greatly promoted the development of smart cities. However, due to the development gap between regions, the smart cities also has enormous regional differences.

Output Effect Analysis of Smart City Construction

The development of smart cities should take into account the sustainable development of cities (Silva, Khan, and Han 2018). The IoT plays an important role in smart cities, which is conducive to promoting urban economic development, reducing energy consumption and improving the urban environment (Almalki et al. 2021). The output factors of IoT in the process of smart city

construction include two aspects: positive and negative. On the positive perspective, the application of the IoT has made urban economy develop rapidly and become a major engine of economic development. This paper mainly studies the Internet output value and postal business income caused by the use of the IoT. With the rapid development of the IoT, it has also brought other problems, such as the increase of exhaust emissions and wastewater pollution. For this reason, this paper analyzes the positive and negative factors caused by the IoT to provide guidance for the healthy development of the IoT, as is shown in [Figure 25](#).

From the positive perspective of the relationship between smart city construction and IoT, the application of the IoT in smart cities has greatly promoted economic development, as is shown in [Figure 26](#). The application of IoT has promoted the rapid development of online trade and changed people's way of life. The rapid development of online trade has promoted the prosperity of online transactions and the growth of postal revenue. According to the correlation analysis between e-commerce sales and postal business income on smart city construction, there is an obvious positive correlation between e-commerce sales and postal business income on smart city construction. To the end, the government should take measures to encourage the development of the IoT to promote the thriving of smart cities.

The application of IoT in smart cities not only brings convenience to urban life, but also brings other problems, such as the discharge of urban wastewater and exhaust emission, as in shown in [Figure 27](#). By studying the linear relationship between smart city and waste water and waste gas, we can conclude that with the blooming of smart city, the urban waste water emission increases with the flourishing of smart city, and the urban waste gas emission decreases year by year with the development of smart city. The reasons for the reduction of urban exhaust emissions are as follows: (1) The progress of IoT technology. The widely application of the IoT, such as urban exhaust gas monitoring system, urban smart tram, etc., have effectively reduced the emission of urban exhaust gas. (2) Government policy support. In order to improve the environmental quality, the government has taken a series of effective measures to promote the development of IoT technology, so that the urban environmental monitoring department can comprehensively supervise the urban air and reduce the emission of urban waste.

Conclusion

Research Conclusion

The application of IoT in smart cities enables all aspects of urban life to be connected through the network, making people's daily life more and more convenient. Based on the studies of the application of the IoT and the smart

city evaluation model in western countries, this paper constructs a new application model of the IoT in smart cities, and analyzes the model through the entropy method, so that we can easily and intuitively clarify the development status of smart cities. Different cities have different emphasis on smart cities development. From the perspective of smart infrastructure, Shanghai is the top city in terms of development. From the perspective of smart living, the development level of Chongqing is far ahead in China. In terms of smart enterprise, the development level of Guangzhou is in the forefront in China. From the perspective of smart transportation, Chongqing is the best developed city in China. From the perspective of smart logistics, Shanghai has the highest level of development in China. The study also found that from 2011–2020, as hot large cities, Beijing (0.1049–0.1132), Shanghai (0.1176–0.1519), Guangzhou (0.073–0.1378) and Chongqing (0.0708–0.1019) have the highest development level of smart cities in China, with an average score of more than 0.1. Chengdu (0.0474–0.0685), Hangzhou (0.0461–0.0632), Fuzhou (0.0253–0.0278) and other cities still have a certain development space for smart city development. Of which those cities such as Lhasa (0.0066–0.0068), Xining (0.0102–0.0117), Yinchuan (0.0116–0.0092) and Lanzhou (0.0122–0.0138) is still relatively low.

The application of IoT in smart cities has promoted rapid development of cities. In order to measure the validity of IoT in smart cities, this paper analyzes the role of IoT in smart cities from the perspective of input and output, and uses the DID model to compare cities with high levels of smart city development with cities with low levels of smart cities development, so as to provide a theoretical basis for achieving regional balanced of the country. Through the research, we find that the application level of IoT in smart cities is positively correlated with the labor and capital investment of cities, indicating that the more capital and labor cities invest in IoT, the higher the degree of smart cities. In addition, from the perspective of the output effect produced by the application of the IoT in smart cities, the application of the IoT has made cities appear new economic growth points and become the engine of urban economic development. However, the application of IoT in cities has also brought a series of problems, such as wastewater pollution, exhaust gas pollution etc. The application of the IoT in smart cities shows a positive correlation with wastewater pollution and a negative correlation with exhaust gas pollution. Therefore, how to reduce the discharge of urban wastewater has become the next breakthrough in the development of IoT technology.

Shortcomings and Prospect

The development of smart cities depends on many technologies, such as blockchain, big data, AV, AI, 5 G, etc (Camero and Alba 2019). The application of IoT in smart cities requires the support of big data, AI and other technologies to better connect various parts of the city and provide better services for people's lives

(Hashem et al. 2016). Therefore, the research in this paper is not comprehensive enough, it only studies the application of the IoT in the construction of smart cities, which cannot fully reflect the application level of technology in smart cities. The development of smart cities is reflected in many aspects, such as smart environment, smart energy (Lazaroiu and Roscia 2012), smart services (Letaifa 2015), smart policies (Willis et al. 2019), smart architecture (Al-Hader et al. 2009). The smart city development model established in this paper is not enough perfect, subsequently research will conduct in-depth analysis of the smart city model to establish a more perfect smart city model. In addition, the development of smart cities is a comprehensive process, involving all aspects of social life. The analysis on input and output factors of smart city development in this paper is not perfect, and a more perfect effect model will be established later to comprehensively evaluate the relationship between the use of IoT and urban development.

A famous English writer, Bulwer-Lytton, Edward G ever said, "Every street has two sides, the shady side and the sunny. When two men shake hands and part, mark which of the two takes the sunny side; he will be the younger man of the two." IoT is a double-edged sword. It promotes the rapid development of smart cities, but it also causes some social problems. To begin with, the application of IoT will not only make people's lives more convenient, but also increase the insecurity of private information. How to ensure the development of technology while promoting privacy security is the bottleneck of IoT. What's more, IoT has led to structural unemployment and increased social instability while creating new jobs. Last but not least, IoT has had a negative impact on social ethics and values. IoT has impacted people's inherent concepts of social responsibility and ethics to a certain extent, and triggered new social problems. Therefore, as the world enters the middle and late transformation stage of the long cycle of information technology revolution, how to improve the innovation governance ability, how to prevent and resolve social conflicts, and achieve more balanced development of society, are another problems facing the modern government all over the world.

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ORCID

Yejin Liu  <http://orcid.org/0000-0002-8356-3081>

Min Ye  <http://orcid.org/0000-0003-0920-7940>

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