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RESEARCH ARTICLE

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The development trend and practical innovation of smart cities under the integration of new technologies

Abstract Smart cities have rapidly developed in the context of the integration of new digital technologies such as big data, Internet of Things, artificial intelligence, blockchains, and virtual reality. These cities have conducted practical innovations and typical cases in many sectors, such as in government, transportation, environmental protection, energy, medical care, and logistics, and have produced many social, economic, and ecological benefits. However, there are still some problems that continue to hinder the construction of smart cities. This paper examines such problems in depth and proposes some relevant countermeasures and suggestions.

Keywords new technology integration, smart city, big data, practical innovation

1 Introduction

In 2008, IBM proposed the "smart earth strategy" and argued that in order to promote the wisdom of the earth, an instrumented, interconnected, and intelligent world should be built by proposing a strategy based on the perception, transmission, and processing of data (O'Grady and O'Hare, 2012). Since then, to cope with the continuous population growth, environmental pollution, traffic congestion, and other "urban diseases" driven by urbanization and to promote the healthy, safe, and sustainable development of cities (Yamamura et al., 2017), the construction of smart cities has become a common pursuit and a trend in global urban development (Albino et al., 2015; Trindade et al., 2017).

Hundreds of cities around the world are building "smart cities" on the basis of "digital cities". For instance, Atlanta, Boston, Las Vegas, Los Angeles, San Francisco, Seattle, Austin, Philadelphia, Cleveland, Marion, Pittsburgh, Milwaukee, and other cities in the US are all building wireless networks. Meanwhile, Dusseldorf, Gyor, Monaco, Westminster, Incheon, Seoul, Busan, Kuala Lumpur, and Sydney are actively building wireless digital cities (Kummitha et al., 2017). In China, the Ministry of Industry and Information Technology has published a list of 68 cities to be piloted as "smart cities", including the provincial capitals of Beijing, Tianjin, and Shanghai, and highlighted the importance of integrating industrialization with informatization. At present, 100%, 89%, and 47% of more than 500 sub-provincial, prefecture-level, and county-level cities in China, respectively, have proposed or are currently building smart cities, as indicated in the government work report for the "13th Five-Year Plan" (Diao, 2015).

With the widespread use of new technologies such as information and communication technologies, cloud computing, big data, Internet of Things, blockchains, artificial intelligence, and Mobile Internet, a new generation of information technologies is being developed to maximize the effective operation of cities and to achieve an efficient information sharing (Joshi et al., 2018). New ideas and models for transforming the Internet, for achieving an intelligent and smart promotion of sustainable development (Bibri and Krogstie, 2017), for promoting urban planning, and for constructing and managing intelligent service providers have also been proposed to create new opportunities for the construction of smart cities.

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2 Development trends of smart cities under the integration of new technologies

2.1 "*2N41*" conceptual framework of smart cities

Smart cities are based on digital, networked, and intelligent information technology facilities (Li and Gan, 2001). With society, environment, and management as their core elements, smart cities are modern cities that benefit both the people and the environment. One conceptual structure of smart cities under the integration of new technologies is "*2N41*" (Fig. 1), which can be divided into four components. The first component "*2*" refers to the hard facilities (e.g., sensing devices, cloud computing infrastructure, mobile terminals, and information service terminals) and soft environments (e.g., policies and regulations, standards and norms, working mechanisms and safeguards, and personnel training) that are relevant in the construction of smart cities. The second component "*N*" refers to the application of knowledge in multiple regions, industries, and fields, including transportation, population, agriculture, environmental protection, and people's livelihood, depending on the present situation. The third component "*4*" refers to the four goals of a smart city, including guaranteeing the happiness of its citizens, promoting scientific urban management, encouraging the innovative development of enterprises, and ensuring a harmonious social operation. The last component "*1*" refers to the best state of urban operation that can be achieved through the construction of a smart city. By strengthening the application of the Internet of Things, cloud computing, video monitoring, and other technical means in urban operation, a smart city operation monitoring and intelligent security emergency response can be realized, the precise management ability of the government can be improved, and the safety and efficiency of urban operations can be enhanced. An intelligent signal control system is established by installing sensors at street intersections, which can automatically monitor traffic flow and speed, realize an automatic optimization, adjust the traffic signal lights according to the traffic flow, and improve the adaptive ability of road traffic. Information technologies, including Internet of Things and new-generation mobile communications, are also employed in the manufacturing of foods, drugs, and hazardous chemicals to dynamically monitor their entire manufacturing process (Hammi et al., 2018).

2.2 Model framework of smart cities

The core objective of a smart city is to serve people (Caird

Fig. 1 "*2N41*" conceptual framework of smart cities.

and Hallett, 2019; Cowley et al., 2018). In the "*2N41*" conceptual framework, the urban system serves as the system application layer, whereas the data flow realized through the Internet of Things and cloud platform serves as the input support layer (Wang et al., 2018). Meanwhile, the "state-led and enterprise participation" mode serves as the essence of a smart city, whereas the enterprise-driven model acts as the implementation path (Chen et al., 2018a).

Figure 2 shows the overall framework of the construction of smart cities under the integration of new technologies. The perception layer is based on the Internet of Things technology and mainly handles tasks related to data perception and information collection. The platform layer mainly analyzes and processes information through various information platforms or components of the carrier network. The application layer acts as the terminal of the entire smart city technology framework and is mainly used for business, personal, and public service applications. A smart city needs to establish a five-in-one network security system of "defense, monitoring, combat, governance, and evaluation" to build a standardized system that meets its needs.

2.3 Development trend of smart cities

2.3.1 Overall trend of smart city development

The overall trend of smart city development is outlined as follows. First, information plays an indispensable role in smart city development. Mobile Internet provides an

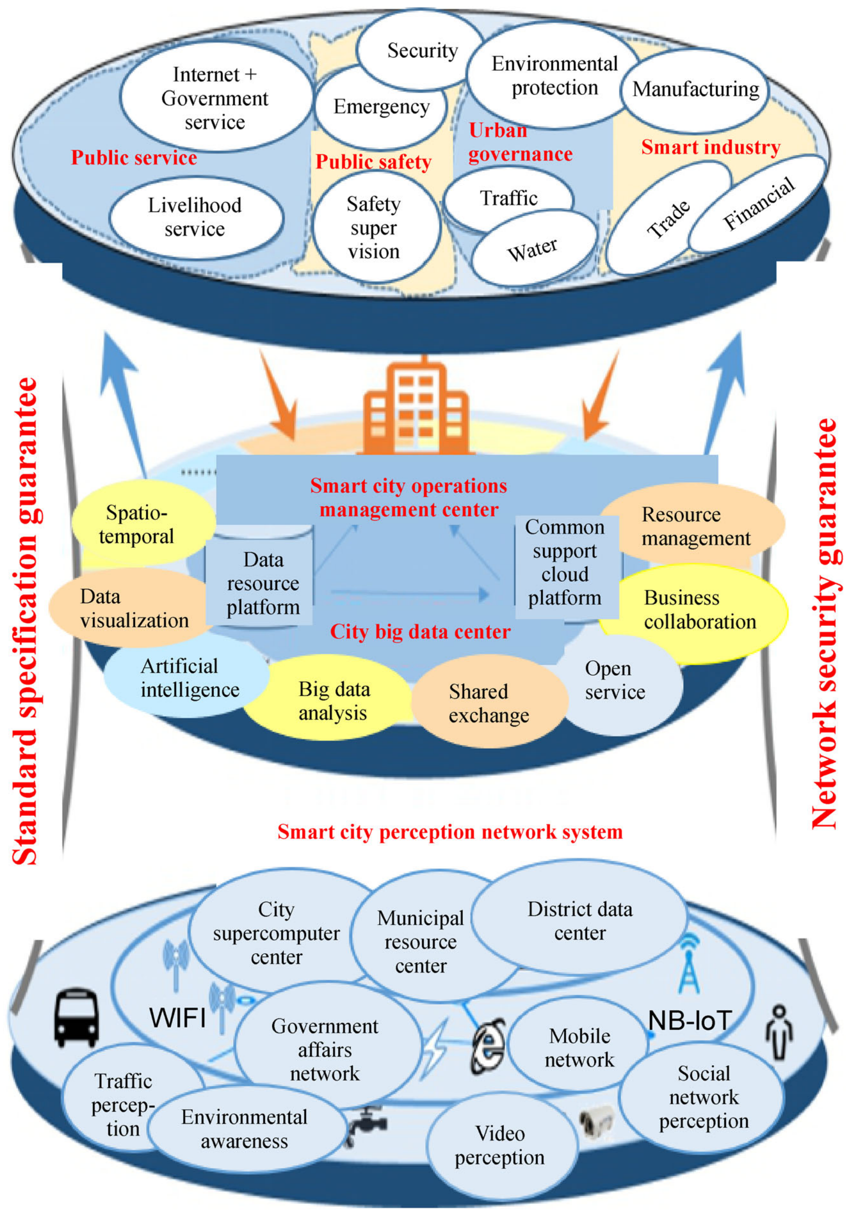

Fig. 2 Overall framework of the construction of a smart city under the integration of new technologies.

excellent channel for people to exchange, collect, transmit, and share information, thereby making this technology a vital part of human life. Second, Mobile Internet has been integrated into the lives of people, changing their living habits, social ways, and relationship networks, and is currently being applied by consumers in every aspect of their lives, thereby creating a "mobile lifestyle". Third, intelligence has become the mainstream. Digitization and intelligence have penetrated all walks of life and have gradually become the center of the current cultural forms, thereby ushering in a new round of cultural ecology. Fourth, information technology is leading the change in the current era. In this way, the developments of big data, cloud computing, blockchains, artificial intelligence, Internet of Things, and other information technologies determine the quality of smart city solutions, and the continuous progress of these technologies will contribute to the continuous transformation and optimization of urban activities. Fifth, the integration of Internet Thinking, which focuses on user, big data, cross-border, platform, and innovative thinking, encourages a re-examination of the traditional value chain and requires the realization of both integrated and application innovations in all walks of life. Sixth, smart cities promote urban development by combining "one center, four platforms, multiple technologies and applications, and unified chains" (Fig. 3), among which, "one center" refers to big data centers that cater to the needs of the city, "four platforms" refer to the integrated information service platforms for smart government affairs, smart city management, smart people's livelihood, and smart economy, "multi-technology" refers to related information technologies, including cloud computing, Mobile Internet, Internet of Things, and artificial intelligence, "multi-application" refers to a variety of smart applications, and "unified chain" refers to a trusted smart city information ecology based on blockchains.

2.3.2 Influence of new technology integration on smart city development

Integrating cloud computing, big data, Internet of Things, blockchains, artificial intelligence, Mobile Internet, and other new-generation information technologies (with data as their core) into data collection, data analysis, data mining, and decision-making services can lead to the formation of an integrated innovation and wisdom model based on the strategic model of "Intelligent System (IS), Integrated Collaboration (IC), Interconnected Empowerment (IE), and Continuous Evolution (CE)" (Lee et al., 2013). This model ensures accurate and effective management and monitoring of smart cities, enforcement of laws, and making of decisions. The integration and innovation of

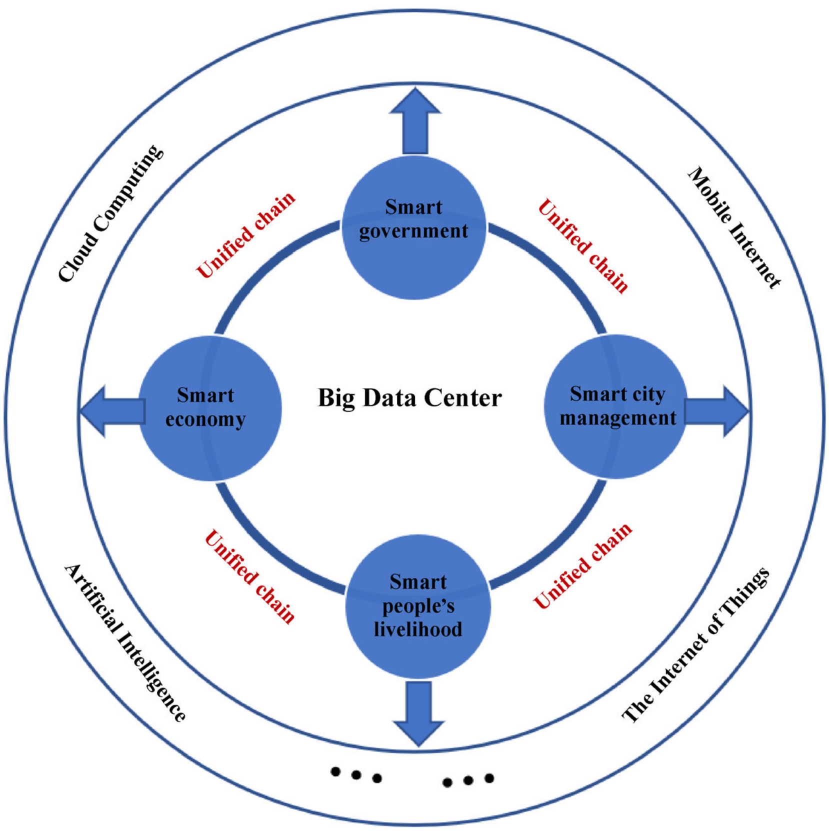

Fig. 3 Overall trend of smart city development.

new-generation information technologies also provide comprehensive support for the construction of smart cities. For instance, the Internet of Things collects city data in real time, Mobile Internet realizes the integration of information and business flows, blockchains allow the sharing, verification, and tracing of collected data and create a data sharing mechanism for big data platforms, and artificial intelligence and deep-level mining promote the formation and development of data-driven urban operation and service mechanism, respectively. In addition, big data mining and analysis serve as bases of urban management and decision-making, the cloud-based construction of data centers can enhance the support capacity of massive data centers, and cloud computing realizes on-demand resource allocation and volume-based billing, and promotes resource scale extension, specialized division of labor, and innovative network services (Souza et al., 2019).

3 Practical innovation in the major fields of smart cities

Smart cities gather not only people but also industries and digital economies. Cloud computing, big data, artificial intelligence, blockchains, and other new-generation information technologies are thoroughly applied in these cities. New technologies emerge endlessly and are rapidly integrated, thereby making the construction of smart cities a reality instead of a possibility. The 2018 China "Internet +" Index Report (Tencent Research Institute, 2018) reveals that China's digital economy volume in 2017 was 26.7 trillion yuan, which was 17.2% higher than that recorded in the same period of the previous year (22.8 trillion yuan) — significantly higher than the GDP growth rate recorded in the same period (6.9%). The booming digital economy and open information market have also promoted the innovative application of smart cities in various fields. The innovation of smart cities driven by new-generation information technologies mainly includes smart government affairs, smart transportation, smart environmental protection, smart energy, smart medical care, and smart logistics, among many others.

3.1 Smart government affairs

3.1.1 Current situation and pain points of government services

The Chinese government has mentioned that in order to modernize the national governance system and the governance capacity, modern information technologies must be utilized to promote government management concepts and social governance models and to ensure that government services are scientific, convenient, and intelligent. At present, local governments in China are actively promoting smart governments and their practical applications. However, several problems have hindered the development of smart governments. First, the quality of the synergy between information and business being used by these governments is far from ideal, and their utilized data are not interconnected. The standards adopted by local governments and their departments also vary across levels, and their business contents are largely monotonous. Application systems are also being planned separately, using different data formats, and running on various platforms, thereby creating obstacles that hinder their coordination and exchange of data. Second, smart governments entail high operating costs. Specifically, the information being recorded and stored in the Internet of Things is aggregated to a central server, and hundreds of millions of nodes generate a large amount of data. Such amount of data is expected to grow in the future, thereby overwhelming the data center, posing difficulties in the calculation, and increasing the operating costs. Third, achieving data security is difficult. In the digitalization of cities, identity services face several problems, including information leakage, identity fraud, and fragmentation, all of which pose challenges to users, devices, and systems.

3.1.2 Changes resulting from the integration of new technologies into government services

The main changes brought upon by the integration of new technologies into government services can be summarized as follows. First, the integration of implied openness facilitates the flow of data among different projects and systems, including roads, warehouses, parking lots, and other infrastructures. Second, smart cities facilitate the sharing of underlying data and business processes and promote data flow, data quality, data security, and data privacy. Third, the comprehensive use of big data, artificial intelligence, and other intelligent technologies can improve the scientific and effective decision-making of government departments, promote the rational allocation of resources, reduce the operation costs of smart cities, and improve their operation efficiency (Sun et al., 2018).

3.1.3 Practical analysis of smart governments

(1) Practical analysis of the Ping An smart government. The China Ping An Group utilizes the comprehensive advantages of "Science + Data + Scenario + Service" to build a platform for integrated security and government affairs; to integrate the four modules of urban planning, collaborative office, analysis and decision-making, and business platform; and to improve the level of government intelligence. This model also provides the government some capabilities in visual city management, big data analysis, auxiliary city operation management, command, dispatch, and supervision visualization, special data

analysis, public opinion monitoring, risk identification, and other functions. The Ping An smart government solution consists of three major platforms and two major systems, as shown in Fig. 4.

(2) Practical analysis of an urban data brain based on “cloud computing + big data + artificial intelligence”. At the Yunqi Conference in October 2016, Hangzhou announced its plans to construct a city data brain. According to the “Hangzhou City Data Brain Planning”, in addition to the city’s transportation sector, this city data brain will also strengthen Hangzhou’s medical, security, urban management, tourism, environmental protection, and other industrial sectors, organize a smart Asian Games event, and create a “mobile city”. This city data brain is the first online government service platform in China to be built based on the Alibaba cloud service at the provincial, city, and county levels. A practical analysis of this smart city is performed based on open data given that “data” is considered as “city infrastructure”, whereas “government data” is considered as “public infrastructure”. In other words, both the city and the government act as platforms of a smart city. As of the first half of 2018, China has successfully launched 46 prefecture-level smart cities that meet the basic government data requirements and promoted the development of a new urban-level data economy by using digital platforms. The operation process of these smart cities is shown in Fig. 5.

(3) Practical analysis of smart governments based on “big data + Internet of Things”. Singapore has established a “citizen-centered” e-government system in which citizens, enterprises, and governments cooperate with one another, that is, citizens and enterprises can participate in various government agencies at any time and place. The construction process is summarized as follows. First, the operations of government agencies in the country are automated to improve the information level of the whole society. Second, the “National Information Technology Plan” (Cook, 2012) is implemented to build a computer network that connects 23 major government departments and promotes the automation and integration of the government’s inter-departmental administrative business processes. Third, a network system that includes a wide range of public services and promotes electronic services that integrate government resources is established. Finally,

Fig. 4 Ping An smart government solution.

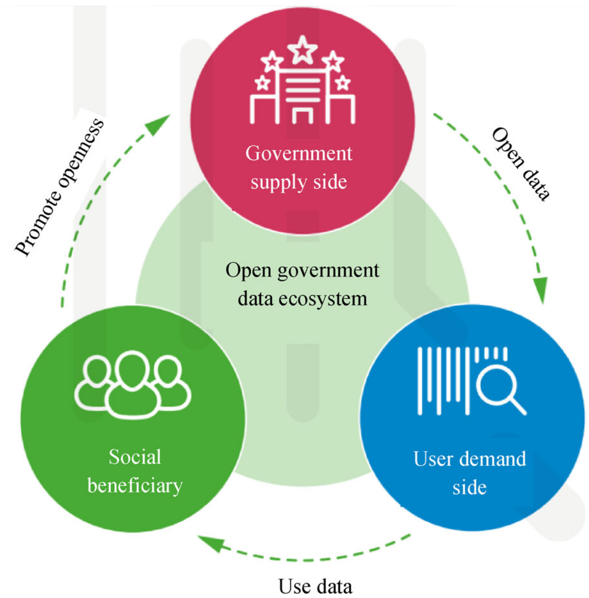

Fig. 5 Operation process of smart city construction based on open data (source: Fudan University digital and mobile governance laboratory).

the main framework of e-government and the specific applications of each level are defined to provide a wide range of public affairs online.

3.2 Smart transportation

3.2.1 Current situation and pain points of the transportation industry

The current situation of China's transportation industry is reflected in the following aspects. First, the contradiction between traffic supply and demand is increasingly prominent. Although China's road transportation and management facilities have greatly changed in recent years, they still cannot keep up with the growth rate of motor vehicles. Most urban road network structures in the country are unreasonable, the road system is unsound, and traffic management facilities are lacked. Moreover, most traffic control centers across different locations only carry out their monitoring functions and completely neglect their control functions. Second, traffic and noise pollution as well as traffic accidents frequently occur in China. Their high frequency not only result in traffic delays and economic losses, but also reduce urban traffic efficiency, thereby influencing economic efficiency and leading to resource wastage and environmental pollution (Zawieska and Pieriegud, 2018). Third, parking is difficult. The needs for motorized development were not fully considered in the design of old residential areas, while new residential areas have been built without taking into consideration the parking demand of residents. Moreover, the public parking spaces in old public buildings are seriously inadequate, and underground parking garages for new public buildings are not in place. Parking information processing is still in its infancy in China, and the on-street parking management mode in the country remains far from perfect.

3.2.2 Changes resulting from the integration of new technologies into the transportation sector

The major changes brought upon by the integration of new technologies into the transportation sector can be summarized as follows. First, the use of the Internet of Things to build a shared smart traffic control platform can help gain a full understanding of the construction of transportation infrastructure via dynamic data collection and analysis, precise control of congestion points, unified traffic scheduling, and monitoring of traffic operations. Second, "big data + artificial intelligence" can help improve data efficiency and can fully exploit the value of information. By revitalizing, applying, and evaluating the existing data, decisions can be made based on these data, so as to facilitate traffic management (Tang et al., 2017). Third, "cloud computing + blockchains" can be used to achieve a secure data storage. Specifically, cloud computing provides a new model for storing various types of traffic data and can be combined with blockchains to ensure data security, break the "information island" phenomenon, and realize information resource sharing and system interconnection.

3.2.3 Practical analysis of smart transportation

(1) Baidu map smart signal light. A customized Baidu map is built by the Beijing Municipal Traffic Management

Bureau as the first urban light-controlled intersection road condition monitoring platform in the country that can realize minute-level detection, real-time alarm, active processing of traffic congestion at signalized junctions, and optimized urban road use efficiency. The Baidu map smart traffic signal light involves three processes. First, the Baidu map can help achieve a comprehensive monitoring and quantitative evaluation of the traffic control capacity of an intersection. Second, by two-way intercommunication, this platform directly communicates with the traffic police signal control system. The real-time result of the platform analysis, as a parameter of signal matching, can affect the real-time operation of the signal light. Third, this platform integrates artificial intelligence technology to achieve local to global optimality, automatically detects problems during operation, and helps achieve a comprehensive intelligent control in real time.

(2) Tencent "Internet +"-empowered smart traffic analysis. Based on Tencent Maps, WeChat, QQ, and other mobile big data, Tencent effectively collects real-time road traffic flow information and creates a smart transportation system based on machine learning and real-time intelligent predictions of human flow distribution (Mohammadi et al., 2018). This system can form a series of social hotspot maps, urban heat maps, urban street views, and real-time road conditions; build traffic big data; perform passenger travel, regional hotspot, behavior trajectory, and traffic congestion bottleneck analyses; and generate statistics of passenger stay time by monitoring road congestions in real time via road cameras. The integration of artificial intelligence can also help predict the occurrence of abnormal congestions, identify the causes of these congestions, and provide technical support for the timely handling of traffic.

(3) Practical analysis of the Didi Smart Traffic Brain. In 2018, Didi Travel and the Ministry of Communications jointly launched the smart city traffic management solution, "Didi Smart Traffic Brain" (Chen et al., 2018b), which has been adopted by more than 20 cities in China. This technology allows real-time data flow through artificial and cloud computing technologies, and integrates powerful and anonymous traffic data and data resources from local governments and business partners, for measuring traffic flow, identifying smart traffic signals and lights, performing traffic congestion and safe driving analyses, and building traffic guidance systems, tidal lanes, and bus dispatch systems.

3.3 Smart environmental protection

3.3.1 Current situation and pain points of the environmental protection industry

The status quo and deficiencies of the environmental protection industry are reflected in the following aspects. First, the potential environmental risks are not sufficiently evaluated. Specifically, the existing environmental monitoring system cannot accurately assess the current situation and change trends of environmental quality and the potential risks being faced in the environment. Second, tampering and forgery of environmental monitoring data occur from time to time. Data quality serves as the lifeblood of environmental monitoring, and the authenticity, comprehensiveness, and long-term nature of environmental data are the most basic requirements for environmental monitoring. Third, corruption of environmental public welfare is widespread. Donations to environmental charities are difficult to track, and bureaucracy, corruption, and inefficiency are rife. Fourth, environmental monitoring data are obviously isolated. Most of the application systems being used in the environmental protection departments of China are built independently, and the lack of overall planning in data sharing and business collaboration lead to repeated constructions and "information island" phenomena.

3.3.2 Changes resulting from the integration of new technologies into the environmental protection industry

A comprehensive monitoring network based on the ecological environment of Internet of Things lays the foundation for smart environmental protection. Sensing, video surveillance, radio frequency identification, and global positioning technologies for the real-time measurement, acquisition, collection, and identification of various data are employed. Blockchains promote the integration and sharing of environmental big data. Using blockchains to track "three wastes" and carbon emissions in production processes can prevent companies and governments from abandoning their environmental commitments or misreporting their progress, thereby discouraging fraud and data forgery. Given their trustworthiness, security, and non-modifiability, blockchains can guarantee an open sharing of environmental big data. Big-data-driven intelligent technologies promote a scientific and comprehensive decision-making process for the ecological environment. Based on the characteristics of environmental data and combined with big data and other technologies, a comprehensive monitoring network can realize the integration and efficient management of environmental big data, and provide comprehensive decision support for environmental monitoring, management of government departments and enterprises, real-time issuance of early warnings, forecasting of regional environmental quality, and identification of environmental policy effects. Some quantitative assessment and optimization methods, and measures for enterprise energy conservation and emission reduction can also be proposed.

3.3.3 Research findings in the field of smart environmental protection

(1) Smart collaborative governance of air pollution in urban agglomerations

Our research team collected about 10 million real-time concentration monitoring data of $PM_{2.5}$, SO_2, NO_x, PM_{10}, O_3, and other pollutants from 23 monitoring sites in the Chang-Zhu-Tan urban agglomeration from the Hunan Provincial Environmental Monitoring Center. These data were combined with more than four million multi-heterogeneous data, including the surface meteorological observation data and traffic flow data obtained from the National Meteorological Data Center, by using big data analysis methods and by taking the Chang-Zhu-Tan urban agglomeration as a typical case system. The atmospheric pollution characteristics in urban agglomerations, the main sources of $PM_{2.5}$ pollution, the effects of environmental policies on improving air quality, the construction of a real-time early warning system for atmospheric pollution, and the relevant strategies for controlling air pollution in urban agglomerations were all investigated. The ArcGIS geographic information system, Kriging interpolation algorithm, and divergence coefficient method were used to analyze the temporal and spatial distribution characteristics of $PM_{2.5}$ pollution in the Chang-Zhu-Tan urban agglomeration. By using the US Environmental Protection Agency PMF 5.0 software and the receptor model (Manousakas et al., 2017), the main sources of $PM_{2.5}$ pollution and their contribution rate in the urban agglomerations were analyzed. The concentration weight trajectory analysis method was applied to calculate the concentration of the airflow trajectory in the potential source area. The degree of pollution across different spatial trajectories was calculated, and a regional $PM_{2.5}$ spatial traceability analysis was carried out (Fig. 6). Based on the results, the "total control area" 3D meteorological field (space dimension + time dimension + element dimension) parameters were identified, and a "localized" WRF–CMAQ (Weather Research and Forecasting model–Community Multi-scale Air Quality) simulation platform was built. The effects of different energy conservation, emission reduction, and environmental pollution control policies on air quality improvement in the Chang-Zhu-Tan urban agglomeration were simulated.

(2) Smart management of the water environment in the Xiangjiang River Basin

Our team has conducted researches on the environmental governance in the Xiangjiang River Basin for many years by using smart water quality automatic monitoring and processing technologies, by collecting and analyzing billions of related data, and by applying multi-source data fusion, environmental assessment, pollution prediction, decision support, and other technologies to formulate a complete solution for environmental big data analysis and application. Other technologies applied in this work include a multi-source data fusion based on the Dempster-Shafer theory (DST) model, an innovative and

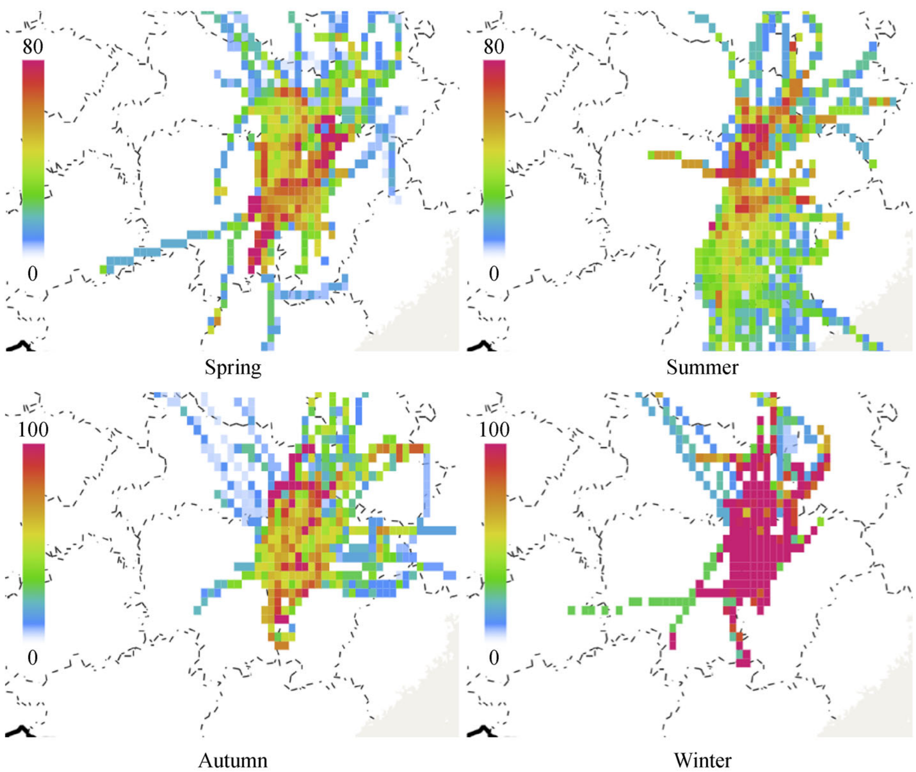

Fig. 6 Spatial traceability analysis of potential sources of $PM_{2.5}$ in the Chang-Zhu-Tan urban agglomeration.

comprehensive evaluation method of water quality based on evidential reasoning and prospect stochastic dominance (mainly to avoid the limitations of using single evaluation index and the incomparability of water quality across different parts of China), and a prediction method for water quality in a river based on improved grey neural network (Mogaji et al., 2015). Based on these results, the changing rule of water quality and the main pollutant sources in the Xiangjiang River Basin were dynamically analyzed (Fig. 7). And the trend of water pollution during the "13th Five-Year Plan" period was predicted to provide an important decision reference for the river basin governance policy-making.

3.3.4 Practical analysis of smart environmental protection

(1) Practical analysis of the environmental monitoring platform. State Environmental Protection Engineering Center for Industrial Pollution Supervising employed the cloud chain technology to develop the "Atmosphere 110" platform, which integrates blockchains, Internet of Things, and big data to offer public services in real time via a positioning system, including atmospheric monitoring and ecological big data analysis, local air condition and pollution mapping, and pollution ranking and comparison. The "Atmosphere 110" platform has diversified data sources and various data products that can meet different data needs of environmental protection departments, research institutes, general public, enterprises, and social organizations.

(2) Practical analysis of the new model of Jinzheng wastewater treatment. Jinzheng—a leading company of special film production and water recycling in China's environmental protection industry—recently collaborated with the NW Blockchain Limited to launch the NewBchain project, which uses blockchains, Internet of Things, and big data to revolutionize current business and operating modes of the wastewater treatment industry and to create an innovative distributed economic business ecology of blockchain wastewater treatment for the world. Creators, participants, or consumers can all participate in the NewBchain to devote positively into environmental protection and wastewater treatment; in turn, they can also consume, trade, and manage their own rights and interests through NewBchain. In this way, the participants of each link of NewBchain can be motivated to promote the development of NewBchain as well as water pollution control and environmental protection.

3.4 Smart energy

3.4.1 Current situation and pain points of the energy and power industry

The status quo and deficiencies of the energy and power industry are reflected in the following aspects. First, building many transmission and distribution infrastructure involves huge monetary costs and transmission losses (among which, the losses between the central power station and the end consumers account for more than 9%). Second, many people are facing the risk of losing power due to reliability problems occurred in the existing power grid and other infrastructure, and maintaining the safe operation of the centralized power grid also involves high costs. Third, the load of the traditional centralized power grid shows an obvious Peak and Valley effect, thereby high requirements are put forward for power generation, transmission, distribution, and storage. Moreover, balancing the load in a centralized power supply system requires great effort. Fourth, although China has many distributed renewable energy sources, problems relating to the consumption and efficient development of these resources are numerous. For example, the surplus power generated by users who have installed solar energy panels cannot be transferred to other users, resulting in energy waste.

3.4.2 Changes resulting from the integration of new technologies into the energy and power industry

The main changes brought upon by the integration of new technologies into the energy and power industry can be summarized as follows. First, integrating the Internet of Things and big data technologies to build a decentralized real-time energy market that connects local producers with consumers can reduce the demand for long-distance transmission. The decentralized power consumption model, based on self-generated energy and supplemented by power grid regulations, is not only greener, but also safer and more reliable than the traditional power consumption model. Second, the decentralized energy trading mode provides additional solutions for balancing the load in the entire power grid. Power grids can mobilize the total amount of energy generated by different consumers by offering economic incentives (e.g., net metering price mechanisms), which can subsequently improve the load balance. Third, integrating such technologies can contribute to the reformation of the power industry (Skouby and Lynggaard, 2014). Smart cities can improve the distribution of their grid infrastructures, and a highly distributed grid is considered highly reliable and efficient in matching energy supply with demand, sending real-time quotation data, and reducing the expenditures for the development of transmission and distribution infrastructure.

3.4.3 Practical analysis of smart energy

(1) Practical analysis of Huawei's oil and gas digital production solutions. Integrating Internet of Things in the production of oil and gas can help monitor the operating

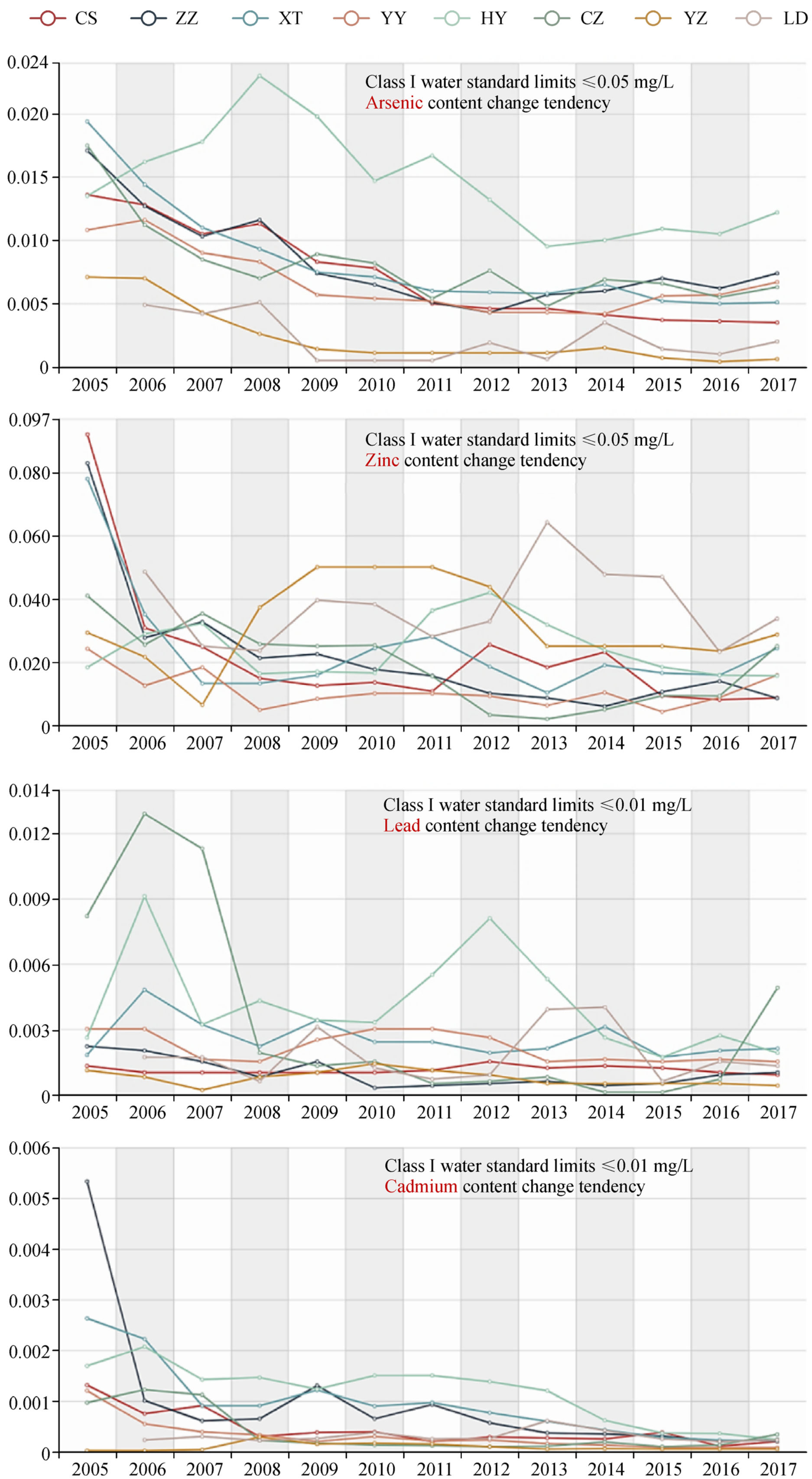

Fig. 7 Temporal variation of four major heavy metal contents in Xiangjiang River (Each line represents a city in Hunan. CS, ZZ, XT, YY, HY, CZ, YZ and LD means Changsha, Zhuzhou, Xiangtan, Yueyang, Hengyang, Chenzhou, Yongzhou, and Loudi, respectively.).

efficiency of production facilities in real time, obtain the yield and ultimate recovery through big data analysis, optimize the production management methods and the organizational structure, improve work efficiency as well as reduce labor intensity, achieve energy saving and consumption reduction, facilitate scientific decision-making, and finally assist in the full digitalization of oil and gas and the digital transformation of oil companies.

(2) Practical analysis of the Chongming smart-grid-integrated demonstration project. The Chongming smart-grid-integrated demonstration project is the first of 55 "Internet +" smart energy demonstration projects that aim to build a three-tier architecture for renewable energy use. First, at the transmission level, by using a "wind-fuel bundling" technology, a coordinated control of green and clean energy sources, including offshore and onshore wind power and large-scale gas turbine power plants, has been realized. Second, at the distribution level, by constructing an intelligent distribution network, friendly access and local consumption of distributed power sources, including wind, light, biomass, and large-scale energy storage, are realized. Finally, in terms of power consumption, by constructing a flexible and reliable intelligent power consumption system, a close interaction between consumers—from industry, commerce, functional system of round-the-island electric vehicles, ecological agriculture, modern urban families—and the power grid can be realized along with an efficient utilization of renewable energy.

3.5 Smart medical treatment

3.5.1 Current situation and pain points of the medical industry

To solve the problems of difficult and expensive medical services, governments and medical institutions at all levels have vigorously advocated medical informatization and hierarchical diagnosis and treatment by integrating various medical technologies, such as electronic health records and other medical IT systems or infrastructure. However, these digital projects are hindered by three major problems. First, the data are scattered and their authenticity cannot be guaranteed. Different medical institutions and information systems create data islands, thereby making it difficult to obtain a unified view of residents. Second, the data are incomplete. For example, the data of patients suffering from hypertension, diabetes, and other common chronic diseases relating to their diet, behavior, or mental health are not digitized or stored in intelligent terminals like wearable devices. Third, data sharing is a difficult task given the low data security and privacy, limited data ownership, and other regulatory mechanisms, which also lead to the reluctance of individuals and data owners to share information.

3.5.2 Changes resulting from the integration of new technologies into the medical industry

The major changes brought upon by the integration of new technologies into the medical industry can be summarized as follows. First, the decentralization and timestamp functions of blockchains have strengthened the error correction and fault tolerance abilities of medical information systems and enhanced the privacy of patient information. For example, the open and non-open code sources combine alliance, public, and private chains to maintain user data security and to generate electronic medical records and inspection reports. Second, the combination of artificial intelligence and big data can help promote precision medicine. Artificial intelligence can help predict the progress of a disease, understand why our bodies respond to different drugs, viruses, and environments, and prevent and diagnose diseases in advance. Third, cloud computing and Internet of Things provide big data support for follow-up medical services (Ning, 2018). Combined with the powerful data storage and processing capacities of cloud computing, the continuous monitoring and collection of patients' physiological data from video and audio devices via the Internet of Things can help provide nursing staff with timely and effective data.

3.5.3 Practical analysis of smart medical treatment

(1) Practical analysis of Hangzhou "Internet + Smart Medical". WeChat offers a "one button" diagnosis function that greatly reduces the registration and waiting time of patients in hospitals. In the course of diagnosis and treatment, municipal hospitals, county hospitals, and community health service institutions in Hangzhou could connect online "smart medical care" services with offline medical services. The online medical services include registration, waiting for treatment, taking reports and medicines, and doctor-patient interactions, whereas offline medical services include consultation, examination, diagnosis, and treatment. In addition, patients are precharged by hospitals to reduce their waiting time for payment. Hospitals in Hangzhou also provide floor settlement services, "trolley-bedside" services, self-service machines, and nurse station settlement services using citizen card in the patient discharge process. Doctors in these hospitals can also provide multi-faceted services. Through the smart medical system, several smart medical functions, such as settlements, examination appointments, and inter-provincial referral appointments during diagnosis and treatment, can be realized.

(2) Practical analysis of the Tencent health manager—"Yijiantong". On July 31, 2018, the Yichang Health and Family Planning Commission collaborated with Tencent to develop "Yijiantong", a health management app that

provides real-time smart reminders for prenatal examinations and fetal development data recordings, intelligent health services during childhood and health self-management after adulthood, and precise care for elderly patients with chronic diseases. “Yijiantong” also uses artificial intelligence and big data technologies to analyze potential diseases and give early disease warnings. When there is a demand for medical treatment, “Yijiantong” provides one-stop medical services, including intelligent triage, registration appointment, online payment, and inspection results checking.

(3) Practical analysis of the construction of a cloud platform for the intelligent analysis of chromosome based on artificial intelligence and cloud computing. On October 29, 2018, the Guangxiu-Zixing Joint Laboratory of Intelligent Medical developed AICKS, a cloud platform for the intelligent analysis of chromosome with automatic recognition and report accuracy of 98% and 100%, respectively. It also has fast analysis speed, short training cycle for zero-based personnel, low labor intensity, low comprehensive costs, and other advantages. In chromosomal karyotype analysis, doctors are usually required to take at least three to five years of training, whereas AICKS learns experiences from senior doctors and can be used by operators with only two months of training. Apart from improving work efficiency, AICKS can effectively solve the problems relating to the inadequacy and irrational allocation of medical resources and promote the implementation of graded diagnosis and treatment in China.

3.6 Smart logistics

3.6.1 Current situation and pain points of the logistics industry

The status quo and deficiencies of the logistics industry are reflected in the following aspects. First, the traditional logistics industry faces some challenges related to information asymmetry and data sharing. Given the limited sharing of information, resources, data, and other elements among logistics enterprises, various types of resources are not fully utilized, which, to some extent, reduces the circulation efficiency of a society’s logistics. Second, the needs of users are diverse and uncertain. In the big data era, by building logistics data application platforms, setting up databases, using data mining techniques to screen customer information, and sharing such information to business and storage enterprises and third-party logistics service providers, an entire supply chain can be built to accelerate responses to customer demand and to offer personalized services to customers. Third, except its high costs, traditional logistics warehousing has low efficiency. In the traditional logistics industry, warehousing operations are carried out according to the instructions specified in the picking form. However, visual errors can easily lead to picking errors, thereby both picking speed and efficiency are extremely low in the logistics industry. Employees also need to understand their storage environment and commodity attributes, which necessitates long trainings, leading to huge consumption of manpower and materials.

3.6.2 Changes resulting from the integration of new technologies into the logistics industry

The main changes brought upon by the integration of new technologies into the logistics industry can be summarized as follows. First, a widely shared intelligent logistics platform is built by using blockchain, which can greatly accelerate the construction of an Internet logistics information platform, then further improve the security and confidentiality of this platform and establish its social credibility. It can also ensure the security of transactions conducted in modern freight logistics platforms, and help the logistics industry reduce its costs and improve its efficiency. Second, personalized logistics services are offered based on big data. Third, artificial intelligence is utilized to create a wisdom center of modern storage systems. Robotic system consisting of rich data perception and artificial intelligence decision-making algorithm become the eyes, brain and limbs of unmanned warehouses. Facing the flow of many goods, robotic system can systematically deploy and operate real-time tracking and network management of storage facilities and goods, with a high degree of sharing of inventory information.

3.6.3 Practical analysis of smart logistics

(1) Practical analysis of Zhiliantong’s “Smart Logistics Sharing Cloud Platform”. In April 2018, Guangzhou Zhiliantong Technology Co., Ltd. established the national “one-stop logistics sharing smart cloud platform”, which ushered in the “blockchain + smart logistics 3.0” era. Through the “flow visibility” of blockchains, the data management in cargo transportation and warehousing is strengthened along with the efficiency of handling, transportation, loading and unloading, and warehousing. Big data ring computing can improve the processing speed of settlement businesses in the express logistics industry. Combining big data with Internet of Things can effectively solve problems related to traceability and anti-counterfeiting of items, and can guarantee the security of information and the privacy of senders and recipients.

(2) Practical analysis of Amazon’s Smart Logistics System. Amazon takes the lead in using big data, artificial intelligence, and cloud technologies in warehousing and logistics management, predictive allocation, and trans-regional and trans-national distribution, thereby establishing a global cross-border cloud warehouse. In Amazon’s operation centers, their intelligent operation system can

direct thousands of Kiva robots to work together through data analysis and algorithms optimization. In terms of logistics planning and preparation, Amazon's intelligent supply chain system performs calculations and analyses based on historical sales data. This system can also automatically accomplish prediction, purchase, replenishment, and distribution of commodities, so that to automatically adjust commodity inventory for accurate delivery according to customers' demand.

(3) Practical analysis of the Ali Cainiao network—an Intelligent Logistics Data Collaboration Platform. Cainiao network uses the logistics cloud platform and big data algorithms to provide intelligent sub-sectors, smart sub-sales, smart cloth distribution, and intelligent route planning. Through the super-robot warehouse group, big data algorithm can help merchants to properly stock up and provide congestion control measures for them, and connect logistics companies to open online and offline supply chains, realizing diversified terminal distribution.

4 Problems and countermeasures of smart city construction

4.1 Problems encountered in smart city construction

The construction level of global smart cities currently is far from satisfactory. Roland Berger recently released the report of "Smart City, Smart Strategy", with a pioneering 100-point smart city strategy index to translate the digitalization of 87 cities around the world, with a view to indicating the direction of smart city strategic planning. The index uses the "action areas" (the scope of the overall smart city strategy application and services), the "strategic planning" (the ability to implement smart city strategies), and the "IT infrastructure" (the technical basis of urban intelligent operations). 12 key indicators are used to conduct researches and evaluations on 87 cities of different scales and different economic strengths, and then the comprehensive scores of each city are calculated and sorted. As a result, the 87 cities around the world have obtained an average score of 37, while only 19 out of the 87 cities have received scores of more than 50. Among Asian cities, Seoul and Hong Kong ranked 8th and 11th, respectively (Fig. 8).

4.1.1 Deficiencies in the top-level design of smart cities

A smart city is a grand social system project that cannot be simply considered as separate smart projects in different fields. How to make overall consideration of information sharing, top-level design and construction planning are the key issues, as they are key components in the construction of smart cities (Huang et al., 2011). The deficiency of top-level design of smart city construction mainly covers two aspects, namely, the national and local levels.

The inadequacies at the national level may involve multi-sectoral inadequacies, strategic inadequacies, and systematic inadequacies. National-level smart city designs include the first "Interim Management Measures for National Smart City Pilots" issued by the end of 2017, the "Three-Year Action Plan for Promoting the Development of the New Generation of Artificial Intelligence Industry (2018–2020)", and 20 other projects that involve the participation of the State Council, Office of the Central Cyberspace Affairs Commission, the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Transport, China National Tourism Administration, the Standardization Administration, and the National Administration of Surveying, Mapping and Geographic Information. The existing policies for the construction of smart cities concerns many fields, both strategic and systematic. However, most of these policies are aimed at the

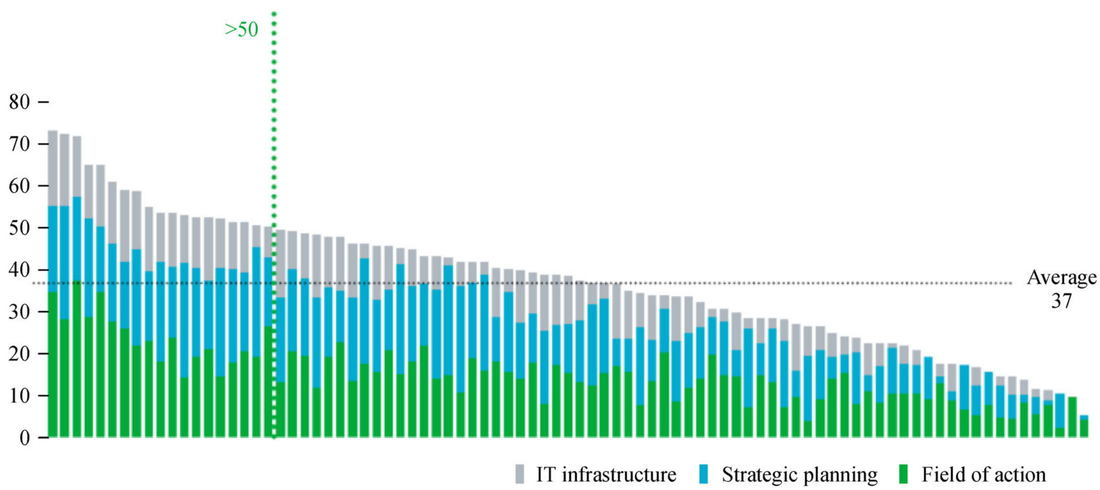

Fig. 8 Smart city strategy index.

construction of smart cities in a single area, and each of the involved departments provides guidance on the construction of smart projects in their respective fields (e.g., transportation, tourism, and e-government). A scientific top-level design for urban system construction strategies at the national level remains lacking.

Some deficiencies can also be observed at the local level, including the lack of social participation, evaluation systems, and continuity. Most smart city construction projects, especially those with a top-level design, tend to ignore non-government-led initiatives. Smart city construction is a comprehensive urban upgrading and reconstruction project that calls for a reasonable division of labor between the government and the market and the construction of a "government + enterprise" business model. In the top-level design, the evaluation indicators of smart city construction and the support from various government departments must be well coordinated. Smart city projects are not overnight successes, but rather dynamically and constantly updated. Therefore, in the top-level design, the scientific research activities about these cities must be planned. Given that many of current top-level urban designs are formulated by certain institutions, these designs would inevitably focus on specific fields, reducing the need for urban characteristics and smart cities. Some of these designs also lack support. In the top-level design, a decision-making mechanism that combines scientific argumentation with administrative examination and approval should be established to give full play to the role of experts, strengthen the substantive and accountability of expert reviews, and provide a greater voice to science and technology.

4.1.2 Data involved in smart city construction are not shared

Data sharing is a core problem of a smart city (Cardoso and Cardoso, 2007). Without solving this problem, smart cities are doomed to fail. Smart cities are currently stuck in a deadlock: Either their data cannot be shared or the shared data are useless. In this case, smart cities are far from realizing "data sharing and business collaboration". It is mainly due to independent data management and unwillingness to open and share among departments. A smart city has more than 20 government administrative departments. The data being used in each of these departments are relatively independent, and the awareness, willingness, and interests of these departments for data opening also differ. Moreover, information systems are not interconnected, and data formats are not uniform. The information systems of various departments are not interchangeable, and the standards of data storage and circulation also vary, resulting in the need of complex solutions. Data sharing cannot be easily unified with privacy protection. In fact, one of the main reasons that prevent individuals from sharing data is their concern for privacy.

4.1.3 Lack of a standardized guidance

Inconsistent standards lead to incompatible systems and difficult integration, which greatly limit the construction and application of smart cities. Given that the construction of smart cities involves many aspects, the existing standards for smart city construction need to be unified and standardized, and new standards must be formulated. For example, the construction of smart cities involves several industries, including manufacturing, information, and biology, with each industry having a different level of technological maturity. Smart cities also have diverse and extensive objectives and applications. The lack of overall planning of the top-level design and the absence of a unified standard can also greatly hamper the integration of various incompatible systems. For example, cameras may be unable to communicate with the traffic light system at the same intersection, thereby making the automatic regulation of real-time traffic flow impossible.

4.1.4 Resource and environmental problems in the construction of smart cities

Resource and environmental problems are prominent in the construction of smart cities. These problems cover three key aspects, namely, urban garbage, shortage of resources, and haze pollution. First, among more than 600 large- and medium-sized cities in China, 2/3 of which are surrounded by garbage, whereas 1/4 of the cities do not have enough place to store their garbage. The urban garbage output of China has exceeded 400 million tons per year. Second, the shortage of water, land, and other resources limit the development of cities. About 20% of the global population have no access to safe drinking water, whereas 40% have no access to basic sanitation facilities. China has 2300 tons of water resources per capita, only about a quarter of the global average. And, the per capita land area of the country is only 0.777 hectares, about 1/3 of the world's per capita land resources. Third, given that the US took 60, Japan and London took 30 years, respectively, to deal with their smog problem, China is still struggling with its air pollution problems, and addressing such problems is considered as a long-term task for the construction of smart cities in the country (Zhang, 2005).

4.1.5 Bottlenecks in smart city technologies

Smart city technologies face several bottlenecks. First, in the development of a smart city, sensors with considerable processing capacity and low energy consumption should be installed. However, these small and high-performance sensors can only be used in cutting-edge fields and cannot be applied on a large scale. Second, many applications in smart cities are automated and do not require human intervention. Such automation may require tens of millions or even hundreds of millions of nodes, which far exceed the original communication scale. Third, dealing with massive amounts of perceptual information in a timely manner presents another technical bottleneck in the development of smart cities. With the deepening construction of smart cities, cloud computing and other technologies need to be utilized to promote the continuous development of platform processing technologies and to address the storage, classification, processing, and retrieval needs of massive data. Fourth, Internet of Things faces some complex security issues, while information security as a topic has not attracted enough research attention. In fact, security is among the key issues that need to be addressed in the development of smart cities. Although China ranks the second best in the world in terms of its Internet and information technologies, the development of such technologies is severely restricted by the US.

4.1.6 Lack of economical and mature solutions

China's existing solution system has poor compatibility and low maturity, leading to high costs, low efficiency, and limited experience in the construction of smart cities. China also lacks a scientific and effective framework for the construction and operation of smart cities.

4.1.7 Lack of in-depth applications

Most smart city applications are still at the infrastructure construction level, and these smart cities lack functions for urban emergency command, decision-making management, public livelihood, and other aspects. A quantitative evaluation of the existing smart cities in China reveals that cities above the prefectural level have an average score of 58 out of 100 and that the smart city construction projects in 70% of these cities are still at the starting or preparation stages (Qi, 2016). Therefore, China still lacks a benchmark smart city.

4.2 Countermeasures for the construction of smart cities

4.2.1 Formulate policies at different levels and design solutions based on local conditions

Different planning and design tasks at the national and local levels must be performed to address the deficiencies in the top-level design of smart cities. The national-level tasks include determining a national strategy for smart city construction and planning and designing its goals, principles, standards, and other macro strategies. A systematic framework for smart cities should be built while considering the interaction among various fields (e.g., transportation, tourism, and e-government) from a macro perspective. Meanwhile, the local-level tasks include establishing authoritative leading bodies and unified coordination mechanisms, and carrying out targeted top-level design and construction plans based on national policy planning, city characteristics, and family background of residents. A comprehensive set of social and economic goals that can benefit people's wellbeing should also be implemented. Smart city construction is a "leading" project. Based on top-level design and overall planning, a smart city application center and operation brain should be established to organize, implement, supervise, and manage the construction of smart cities.

4.2.2 Promote data sharing through administrative and technical means

Sharing government data through administrative means facilitates the dissemination and integration of public data from various government departments. The problems related to sharing sensitive and private data can be solved by technical means in three ways. First, relevant laws and regulations must be implemented to break the barriers that hinder the sharing of public data. Second, sensitive data should be desensitized and should not be shared openly to the public. Data analysis in smart cities is not specific to individual information. In this case, data desensitization can effectively prevent the leakage of personal, business, security, and other sensitive data. Third, blockchains and smart contracts must be used to separate data ownership from data usage. Data ownership and the right to use are often bound together, thereby creating a barrier to data sharing. How to activate digital assets in data warehouses while protecting the rights of data owners has become one of the main problems being faced by smart cities.

4.2.3 Design an overall framework of standards and promote the formulation of standards in stages

The construction of smart cities cannot be completed without standardization. A smart city standard system must be built to facilitate urban reform, and the relevant technical and industrial standards must be issued to guide the operation of emerging industries and the cross-border integration of different industries. Standardization can be achieved in several ways. First, China should establish national smart city standardization promotion organization and mechanism that suit the characteristics of its smart city construction project, facilitate the coordination, liaison, and communication among various departments, and fully utilize the enthusiasm of stakeholders. Second, an overall framework of standards should be designed to meet the needs of smart city construction and management and to ensure that the construction of smart cities is following certain standards. Third, the existing standards should be considered and new standards must be formulated in stages. The construction of a smart city standard system not only involves the integration of existing standards but also the investigation of the emerging industrial technologies and management standards. We should also pay attention to the maturity and stability of these standards. Fourth, the development of smart cities should focus on the integration of systems and various standards across industries. Given that smart cities are carriers of relevant technologies, inter-industry standards should be formulated as soon as possible to guarantee the sustainable construction of these cities and to realize the integration of their functional information systems.

4.2.4 Innovative technologies driving urbanization

Innovative technologies are driving urbanization. On the one hand, these technologies promote the development of sensors and wireless sensor networks with excellent performance, low energy consumption, and low costs, thereby facilitating the realization and expanding the scope of various smart city applications. These technologies mainly include network topology control, multi-hop reliable data interaction, channel resource scheduling, physical layer technology, collaborative computing and processing, distributed information perception, and other technologies. On the other hand, the network capacity needs to be enhanced. The adaptability of the communication network of a smart city should be evaluated. And based on the characteristics of this network, including its operation and maintenance, a network capacity improvement plan that adapts to and meets these characteristics should be formulated. The mechanisms of network layer business characteristics management, network resource allocation, network performance optimization, flexible QoS (Quality of Service) system, flexible network security capabilities, and mobility management also deserve considerations.

4.2.5 Achieve a smooth transition to the green smart city

To achieve a smooth transformation into a green smart city, several aspects must be considered. First, the “red line thinking” must be upheld and a green urban development system must be established. Second, the institutional control over urban processes, urban air quality, water and soil environments, and consumption efficiency of resources and energy must all be improved. Third, the development and growth of smart environmental protection must be promoted through innovation. Fourth, the new generation of information technologies, including big data, artificial intelligence, Internet of Things, and cloud computing, should be integrated to create a new intelligent, environment friendly, real-time, and sky and earth integrated green governance system. Fifth, stakeholders must be encouraged to participate in the urban eco-environmental protection and social service market, their environmental protection efforts must be guided, the social development of organizations must be supported, the participation of citizens in regional public policy formulation and administrative management processes must be encouraged, the characteristics of the Internet era must be exploited, and the use of a convenient, shared, interactive, and efficient electronic governance model must be promoted.

4.2.6 Support industries, pilot projects, and build smart city application demonstrations

The demonstrations of smart city construction should focus on several aspects. First, these smart cities should support the development of relevant industries. Second, all departments of these smart cities should consider the constraints; encourage collaborations among multiple sectors, industries, and enterprises; promote synergy; and conduct pilot studies to test and improve their proposed solutions for data collection, openness, privacy protection, construction of public platforms, data flow among departments, and evaluation of smart city construction performance. Third, innovations and their integration must be promoted. Enterprises should be encouraged to share their technological innovations, explore their business models, consider those problems that they may face in their application of new technologies and models, avoid conceptual hype, deepen the application of smart city construction, motivate technical exchanges among industries, and provide solutions for the expansion of smart cities.

5 Conclusions

Smart cities serve as blueprints for ideal city life, but they are still far from reality. We need to maximize our utilization of new technologies, seize the opportunities brought by urbanization, constantly improve the top-level design of smart cities, promote data sharing, formulate new standards, and integrate and deepen the application of technological innovations, in order to turn these blueprints into reality.

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