New Opportunities in Urban Science Research (Postprint)

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Abstract

Urban science is the study of urban issues from the perspective and with the methodologies of systems science. As urban development enters a critical period of quality enhancement, transformation, and structural adjustment, advances in digital technology and the development of the digital economy have brought new opportunities for urban science research. By reviewing the theoretical connotations of Qian Xuesen's urban science, drawing upon the frontiers of international urban science research, and integrating the goal support, key challenges, and application scenarios of China' s new smart city construction, this paper proposes the contemporary requirements for elevating the research level of urban science, with a view to endowing the future development of urban science with new ideas and connotations.

Full Text

New Opportunities for Urban Science Research

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Abstract

Urban science is the study of urban problems from the perspective and through the methods of systems science. As China' s urbanization rate has reached 65.22%, urban development has entered a critical period of quality improvement and structural transformation. The advancement of digital technologies and the growth of the digital economy have created new opportunities for urban science research. By reviewing the theoretical foundations of Qian Xuesen' s urban science, drawing on international frontiers in urban science research, and examining the goal support, key challenges, and application scenarios of China' s new smart city construction, this study proposes contemporary requirements for elevating urban science research, aiming to imbue the future development of urban science with new ideas and connotations.

Keywords: urban science, system thinking, digitization, new smart city, urban transportation

1. Overview of Urban Science Research Status

Urban modernization is the result of keeping pace with the times and self-renewal, and represents an important symbol of national modernization [Figure 1: see original paper]. The 20th National Congress of the Communist Party of China outlined five characteristics of Chinese modernization: modernization of a massive population, common prosperity for all, coordination of material and spiritual civilization, harmony between humanity and nature, and peaceful development. These characteristics determine the fundamental principles of China' s urban development and reflect the highly comprehensive and complex nature of urban modernization.

Given the extremely broad scientific questions encompassed by cities, involving numerous contents and populations, and with rapid changes in economic, social, and information technology development, urban complexity is increasing daily. Therefore, it is necessary to apply "system thinking" to understand cities and utilize complexity science methodologies. Urban science research must adhere to a comprehensive integration method combining qualitative and quantitative analysis [Figure 2: see original paper]. This involves: first, establishing empirical hypotheses (judgments or conjectures) through qualitative analysis; then testing their validity using empirical data, materials, and models; and finally, deepening understanding of the actual system through quantitative modeling and simulation analysis, forming conclusions and recommendations that inform public policy decisions. Throughout this process, urban science research must be oriented toward practical urban work, grasp development patterns, focus on key areas, and serve the realization of national modernization and urbanization strategies.

1.1 Domestic Perspectives on Urban Science

"To solve complex urban problems, we must first clarify a guiding ideology—theory" [1]. In 1985, Qian Xuesen first proposed the concept of establishing "urban science" in his article "Tentative Ideas on Establishing Urban Science," stating that "urban science studies the city itself; it is not rural sociology or urban sociology, but the science of cities—the scientific theory of cities." The traditional "reductionist" approach, while achieving tremendous success in natural sciences, is ill-suited for solving urban problems that intertwine natural and social sciences. With urban science, urban development planning can have a proper theoretical foundation. Urban science is an applied theoretical science that combines engineering technology and basic science [1], representing an intermediate level between theoretical science and engineering technology. Research in such a science requires: guidance by Marxist philosophy; application of systems science perspectives and methods [2]; and organization of multidisciplinary participation to explore systemic patterns and advance the construction and development of urban science systems.

Qian Xuesen [3] particularly emphasized the fundamental relationship between "human" and "artificial intelligence technology" in studying open complex giant systems: "Of course, we must rely on computers, knowledge systems, artificial intelligence, and other technical means, but we cannot completely depend on these machines. Ultimately, we must rely on people, on human wisdom." Urban models, leveraging computer computational power, are theoretical abstractions of cities as complex systems, designed to simplify system details while retaining key elements and structural characteristics, using mathematical tools to simulate urban system operations [4]. However, urban models should not be detached from specific policy objectives and decision-making contexts, nor should they blindly pursue system "optimal solutions" based on single model types and particular assumptions. Human wisdom and judgment must play a role, adhering to an attitude that opposes mechanical materialism and upholds dialectical materialism [5]. By establishing machine models based on expert qualitative analysis, decision-makers can compare multiple policy scenarios before implementation, thereby avoiding potential policy pitfalls.

1.2 International Research Progress

The earliest international discussions on urban science can be traced to the early 20th century. British planning theorist Patrick Geddes [6], in his 1914 book *The Evolving City*, proposed that urban science is history, science, philosophy, and art, as well as politics. The focus of urban science is urban research required for "the path to the new technological city"—the integration of previous disciplinary knowledge, thorough investigation of urban and residential life, in-depth analysis of urban problems, and exploration of urban personality and spirit. This perspective highlights the technical, comprehensive, and interdisciplinary nature of urban science .

Overall, Western urban science research since industrialization can be divided into three paradigms: normative theory, synergism, and political process [7]. Early post-war urban theory and practice focused on what kind of urban environment should be created and how to implement corresponding urban planning schemes. By the late 1950s, normative theory centered on physical design faced significant challenges. With the quantitative revolution, urban research gradually shifted to a synergistic systems perspective, viewing cities as complex wholes where different land-use activities are connected through transportation or other communication media. Different parts of the city are interconnected and interdependent, with urban research aimed at system analysis and control. The political process perspective reflects on "technologism," recognizing that cities are essentially closer to governance. Urban research should not be simple technical evaluation but closely linked to public value judgments, involving assessment of costs and benefits for different populations and their distribution—essentially public service improvement based on public participation.

With rapid changes in information network technologies such as big data, artificial intelligence, cloud computing, and the Internet of Things, new urban science focusing on emerging technology-city interactions has emerged, revitalizing traditional urban science with distinct digital age characteristics. Michael Batty [8], a representative of the new urban science school, points out that cities are primarily bottom-up complex systems whose scale and form follow expansion patterns resulting from spatial competition. Understanding cities requires comprehending not only urban space itself but also how flows and networks shape urban space. Digital information technology has become highly integrated with cities, used to manage, control, and design them, providing new perspectives and methods for understanding urban construction and operation, enhancing urban intelligence, and building a new urban science. Batty combines mathematical theoretical models with urban practice, using geography as a starting point to propose basic technical logic for new urban science modeling, visualization, and simulation based on complex systems theory and network theory. Against this background, academia has established a series of international journals centered on new data, technologies, and methods to advance new urban science research .

2. Application Foundation for China' s Urban Science Development

2.1 Industrial Support for Digital China Construction

(1) The digital economy is a crucial component of the overall Digital China layout, driving profound changes in production, lifestyle, and governance through digital transformation. As a new economic form following agricultural and industrial economies, the digital economy relies on data resources, leverages information networks, integrates information and communication technologies, promotes digital transformation of all factors, and enhances both fairness and efficiency. Despite significant economic downturn from 2020-2022 due to COVID-19, the digital economy core industries grew faster than the average industrial growth rate, supporting economic recovery. In the first three quarters of 2022, computer, communication, and other electronic equipment manufacturing value-added grew 9.5% year-on-year, 5.6 percentage points higher than industrial enterprises

above designated size and 6.5 percentage points higher than GDP growth. Information transmission, software, and IT services grew 8.8%, 5.8 percentage points higher than GDP growth. Digital economy production strongly supported economic recovery and played a crucial role in pulling up GDP growth. Despite pandemic impacts, economic growth in the first three quarters of 2022 still increased by 0.5 percentage points compared with the first half of the year.

(2) Coordinated advancement of digital industrialization and industrial digitalization. The 2021 Government Work Report emphasized "accelerating digital development, creating new advantages for the digital economy, and collaboratively promoting digital industrialization and industrial digital transformation." Digital China' s layout provides an industrial foundation for urban science development, with digital industrialization and industrial digitalization serving as important supports. Digital transformation and information industry-driven changes in production, lifestyle, and governance models, along with leapfrog development of new-generation information technologies such as artificial intelligence and big data, have laid a solid foundation for the evolution of smart cities in the digital economy era.

(3) Digital industrialization, as a leading industry in China' s digital economy, has achieved high-speed growth. Digital industrialization—the information industry—constitutes the foundation of the digital economy, including electronic information manufacturing, information and communication, and software services. In 2021, China' s large-scale computer, communication, and other electronic equipment manufacturing, large-scale software industry, and large-scale internet and related services revenues grew from 10.6 trillion, 5.5 trillion, and 0.71 trillion yuan in 2017 to 14.1 trillion, 9.5 trillion, and 1.55 trillion yuan respectively in 2021, significantly driving industrial production. In 2019, the information and communication technology-based portion of China' s digital economy accounted for 37.8% of the total [10]. The big data industry grew from 470 billion yuan in 2017 to 1.3 trillion yuan in 2021. In the software industry, cloud services and big data services generated 776.8 billion yuan in revenue, up 21.2% year-on-year; e-commerce platform technical services generated 1.0076 trillion yuan, up 33.0% [Figure 5: see original paper]. The industrialization, commercialization, and marketization of data elements continue to expand, with the digital economy becoming the primary economic form and key growth driver following agricultural and industrial economies.

(4) Industrial digital transformation continuously improves development quality and efficiency. Through digital upgrading, transformation, and reconstruction of traditional industrial chains [12], economic output and efficiency increase. Agricultural digital transformation, such as information technology retrofitting of agricultural machinery, has entered various fields including planting and breeding. The Ministry of Agriculture and Rural

Affairs has supported nearly 300,000 sets of agricultural machinery information technology retrofitting through pilot demonstrations. Deep integration of informatization and industrialization in manufacturing has been achieved, with over half of enterprises nationwide realizing comprehensive digitalization in key business segments of production and operation processes, reaching 52.1% in 2022. "5G+Industrial Internet" has been applied and promoted in 22 key national economic sectors including mining, power, and steel, supporting cost reduction, quality improvement, and efficiency enhancement in the real economy. China's online retail sales reached 13.09 trillion yuan in 2021, accounting for nearly one-quarter of total retail sales of consumer goods, up 14.1% year-on-year. Cross-border e-commerce import and export volume grew 15% year-on-year. Digital technology is accelerating integration with various industries. By December 2021, online office, online medical care, and online food delivery users reached 469 million, 298 million, and 544 million respectively, up 35.7%, 38.7%, and 29.9% year-on-year. Digital transformation in industrial sectors and development of smart manufacturing, through technological progress to reduce costs and increase efficiency, optimize process flows and resource allocation, significantly improve product and service efficiency across industries, and reduce environmental impacts including greenhouse gas emissions, meeting new sustainable development requirements in the era of ubiquitous connectivity.

(5) Integrated development of the digital economy and information industry is the foundation for accelerating urban science construction. The inherent demand for China' s new urbanization development compels urban science to adopt new-generation information technology as a driving force. In recent years, China' s digital technology innovation capability has rapidly improved, with emerging technologies such as artificial intelligence and big data joining the global first tier, and the digital economy achieving leapfrog development, laying a solid foundation for the evolution of smart cities, planning transformation, and response strategies in the digital economy era. In 2021, China' s digital economy reached 45.5 trillion yuan, accounting for 39.8% of GDP [Figure 6: see original paper], ranking second globally in total volume, though still far behind the United States—China' s digital economy is only 46.4% of America' s. According to the China Academy of Information and Communications Technology' s *Global Digital Economy White Paper (2022)*, the average digital economy among 47 countries accounts for 45.0% of GDP, with Germany, the UK, and the US exceeding 65% [11]. In summary, as cities continue to develop, China' s requirements for intelligence and informatization are increasing, though the development foundation and capabilities still have room for improvement. New smart cities characterized by thorough perception, interconnectivity, and intelligent applications have become the advanced form of urban informatization, and urban science construction is expected to achieve new breakthroughs.

2.2 Goal Support for New Smart City Construction

(1) Drawing on urban grid management experience to advance smart city and new smart city construction. In 2004, Beijing' s Dongcheng District pioneered a new digital urban management model by developing a "grid-based urban management system." After subsequent pilot programs and comprehensive promotion, urban grid management has laid an extensive foundation for smart city construction. In 2012, the Ministry of Housing and Urban-Rural Development issued the "Notice on Launching National Smart City Pilot Work." In 2016, the "Notice on Organizing New Smart City Evaluation Work to Promote Healthy and Rapid Development of New Smart Cities" introduced the concept of new smart cities, making new arrangements for smart city construction. Urbanization strategies lead to accumulation of urban elements. Seeking development through transformation [13] and timely reforming urban governance models are essential for new urbanization development.

(2) Integrating Geographic Information Systems (GIS) and Building Information Modeling (BIM) to support City Information Modeling (CIM) platform construction. In past and current urban construction management, GIS provides a basic framework for holistic data management, integrating surface distribution features and building external environment information, while BIM provides precise information models for individual buildings, expressing detailed local structures and managing building lifecycle information [14]. Future new smart city construction requires deep integration of GIS and BIM as underlying frameworks to form CIM platforms, establishing an organic complex of urban spatial models and urban information. Data granularity must be further refined to upgrade traditional static GIS-based digital cities to dynamic, perceptive, interactive digital twin cities based on CIM, supporting data sharing and business collaboration throughout urban planning, construction, and operation, and enabling more refined and agile urban governance.

(3) Combining the "14th Five-Year Plan" for new infrastructure construction to promote widespread application of CIM platforms in urban science research. Currently, China' s urban science remains in the primary stage of understanding and describing current conditions. New urban science development requires more efficient application of information technology to conduct holistic pattern recognition and digital description of research objects. On this basis, CIM platform construction can provide data analysis, modeling applications, and simulation platforms for cities, helping urban science research shift from a "technology" path to a "technology-society" framework [15]. In October 2021, the State Council' s executive meeting reviewed and approved the "14th Five-Year Plan" for new infrastructure construction, proposing to "promote the application of CIM and digital twin technology in urban operation and management services." This demonstrates that new smart city construction is inseparable from

foundational CIM platform support.

3. Typical Practical Explorations in Urban Science Research

3.1 Shanghai' s Urban Grid-Based Integrated Management System

Urban science research drives the digital transformation from urban informatization to smart cities, supports the realization of real-time, dynamic, refined management models, and forms a mutual feedback mechanism with urban science theory, methods, and data resource systems. Shanghai' s urban grid-based integrated management system exemplifies how urban science research supports CIM platform application construction, forming a mutual feedback mechanism that drives smart city digital transformation.

Since 2005, Shanghai has gradually built a comprehensive urban management information platform centered on the urban grid management information system and interconnected with other relevant industry management information systems. This platform has the capability to supervise urban management issues within urban public spaces from discovery to resolution. Utilizing cloud computing technology and relying on Shanghai' s e-government cloud, it has established a data sharing and exchange management system, a data governance and monitoring system, and a data analysis and empowerment system, refining government workflows into case filing, processing, and closure. The platform enables applications such as urban physical examinations and data analysis for the "One-Net-All-Services" initiative of the Shanghai Housing and Urban-Rural Development Commission, achieving model innovation in normal and long-term urban management [17]. Additionally, Shanghai' s ongoing CIM platform construction and application builds upon basic geographic information to establish three-dimensional digital models of buildings and infrastructure, expressing and managing urban three-dimensional space. By constructing a digital virtual city that maps, monitors, analyzes, and simulates the physical city, it provides a "three-dimensional spatial baseboard" with full space, full elements, and full lifecycle for refined urban governance and smart city construction.

3.2 Modern Metropolitan Area Identification Method

Urban science research aims to improve urbanization strategies and better promote people-centered urbanization. Urban science theory not only studies theoretical issues but also explores research scenarios integrated with digitalization. In 2019, Wang Guangtao et al. [16] systematically discussed the connotation of China' s modern metropolitan areas and constructed an identification method. This research represents a typical practice that enhances urban planning scientific levels based on urban science system theory and digital technology analysis capabilities.

The research team used big data empirical analysis to clarify that China' s modern metropolitan areas should adopt the "one-hour transportation circle" as the scope definition standard. While international metropolitan areas often use a commuting rate threshold (15%) as the definition standard, big data empirical research on nearly 40 large, mega, and super-large cities revealed that most cities' commuting spatial scales are smaller than administrative boundaries. Therefore, metropolitan area definition methods need adjustment based on China' s national conditions. Leveraging big data' s quantitative analysis capabilities for metropolitan area definition elements such as population flow and industrial linkages, the team proposed using inter-administrative district commuting connections and network connectivity indices to delineate the primary hinterland (core circle), and using district/county population density, proportion of investment attracted by districts/counties to central cities, and business travel flow ratios to delineate the secondary hinterland (associated circle).

3.3 Data-Driven Urban Transportation Service Level Improvement

Urban science advocates interdisciplinary integration and accelerates transformation of knowledge production methods. Viewing urban transportation issues from a sociological perspective allows quantitative empirical analysis of urban residents' travel behavior and experiences based on multi-source heterogeneous data, providing scientific basis and solutions for rational allocation of urban public resources. This interdisciplinary innovative research demonstrates superior analytical capabilities and practical value.

A study on public service accessibility and transportation service improvement for youth well-being, conducted by Tongji University' s Urban Mobility Institute, applies urban science theory with a social equity orientation, using spatiotemporal and text data analysis techniques to explore how public service accessibility affects youth well-being and propose urban and transportation planning improvements. The research team proposed a spatiotemporal accessibility measurement model for public services based on youth travel preferences using multi-source data. Innovatively, they developed a well-being analysis method based on emotional characteristics using social media data and machine learning algorithms. Through one-way ANOVA and generalized additive models, the team studied the relationship between public service accessibility and youth emotional characteristics, confirming their close correlation. Based on these findings, the team proposed targeted recommendations for transportation infrastructure construction and public service provision methods, constructing an interactive feedback methodology system between urban research and planning applications.

4. Contemporary Requirements for Improving Urban Science Research Levels

4.1 Guiding Urban Science Research with the People-Centered City Concept

(1) Promote integration of urban planning, construction, and management to achieve higher-quality urban governance modernization and smart city construction. Using data foundations and development patterns to break through vision limitations requires expanding the depth and breadth of urban science research, exploring digital empowerment scenarios across the entire industrial chain, and clarifying technology application directions based on human-scale perspectives. Develop data-augmented design that applies verified "present" patterns and "past" data to "future" design creation [17], constructing human-scale urban spaces. For example, reserving transformable construction space in built-up areas can enable urban function reorganization through later management adjustments to achieve urban renewal effects.

(2) Research and formulate an indicator system for Chinese urban modernization. Building upon the *New Smart City Evaluation Indicators* system for prefecture-level and above cities, construct evaluation indicator systems for different city sizes and regions. Adhere to the inter-departmental joint meeting system and promote steady progress. Uphold Party leadership, respect urban patterns, and formulate Chinese-characteristic urban modernization development indicators based on problem-oriented approaches to provide roadmaps for China' s urban construction [21].

(3) Bridge the gap between technology development and administrative management by establishing foundational information platforms for data integration and business collaboration. As global development becomes increasingly dominated by the information industry, new-generation information technologies such as the Internet of Things and blockchain are accelerating breakthroughs and integrating into all aspects of economic and social development, becoming key forces in global resource reallocation and economic restructuring [18]. Under these premises, fully developing and releasing data value has become paramount for digital economy and urban science development. The enhancement of digital technologies—including data collection, processing, analysis, model building, algorithms, and computing power—should serve as the technical pillar for urban science development. Focus on challenges such as data aggregation and comprehensive application from various sources, building bridges across the data communication gap between technology developers and administrative managers, and promoting more open government-enterprise cooperation through public data sharing.

(4) Address four major challenges: data standardization and governance, independent and controllable information security, sustainable research and

development, and more open government-enterprise cooperation. Improve capabilities in virtual design and construction, digital integrated management and delivery, and digital platform support to achieve a leap from efficiency to effectiveness in resource allocation [12], and more effectively utilize digital platforms to empower management, technology, and data in urban development. Establish globally linked data integration [19] and business collaborative CIM platforms, which face both software and hardware challenges requiring breakthroughs; learn from and draw on advanced technologies, enhance independent innovation capabilities, and promote relevant technology research and development—using software development to drive hardware manufacturing.

4.2 Building Modern Cities Through Theory-Practice Integration

(1) Widespread application of CIM platforms in urban planning, construction, and management. Considering the complexity and diversity of urban systems, intelligently assist in solving urban problems [20]. Multi-department collaboration should drive selection and research and development of key core software, supporting local innovation according to local conditions. Based on current new smart city indicator systems, adhere to the principle of prioritizing urgent needs, with local city governments organizing collaborative efforts between technical and administrative management personnel.

4.3 The Supporting Role of Urban Transportation Science in Perfecting Urban Science Development

(1) Urban transportation emerges because of cities, and urban transportation science inherits the systems thinking and scientific paradigm of urban science. The symbiotic development of cities and urban transportation is a fundamental characteristic. The research objective of urban transportation science is to serve human needs and organize sustainable, efficient, safe, and low-consumption (low energy, low pollution) urban operations. Urban transportation science emphasizes using multidisciplinary thinking and systems approaches to study coordinated and sustainable development between cities and transportation. Its research fields include not only traditional areas such as urban transportation planning, public transport operation management, and transportation network construction reexamined with new perspectives and concepts, but also new situations and tasks facing urban transportation in the transition from traditional social management to social governance.

(2) The research object of urban transportation science is the construction and operation of urban transportation composite networks, understanding urban development and operation patterns from a dynamic perspective. Urban transportation research examines human travel demand within existing urban frameworks, studying relationships between people, vehicles,

roads, and environments, as well as services provided by transportation modes (including passenger and freight). Faced with diversified economic and social production and lifestyles, innovative technological development, modernization of transportation tools, and particularly society’ s high requirements for green development, urban transportation is no longer merely about infrastructure and vehicles. Therefore, urban transportation research must study urban transportation issues from a broader perspective of serving human needs, more importantly reflecting the city’ s overall comprehensive service functions and operational benefits.

(3) Data resources and model methods from urban transportation network operation can serve as important foundations for perfecting urban science theory and empirical research. The urban transportation research field possesses extensive urban-related data accumulation, including comprehensive transportation surveys recording movements of people, vehicles, and goods; the four-step transportation model containing population, travel, and land-use data; and urban big data represented by mobile phone signaling, geographic location data, and bike-sharing trajectory data. These provide rich data resources for quantitative empirical research in urban science. Moreover, urban transportation research has a relatively complete model methodology system, including cutting-edge analytical methods such as machine learning, deep learning, and complex networks applied in the field. These data and model methods provide necessary conditions and rich resources for verifying and developing urban science theory, holding important foundational value for enhancing urban science research levels.

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Note: Figure translations are in progress. See original paper for figures.