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Smart Mobility over the Future City

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Abstract: Standing on the evolution trends of future city and mobility, this paper summarizes the four core features of future city and mobility. With smart governance-and sophisticated services-oriented, an integrated solution to smart mobility for next generation city, including ubiquitous perception city, real-time deduction city, smart managing city and all-aspect serving city ("4C" for short), is proposed to better establish the smart mobility in the future. The paper tries to explore a smart path using frontier technology such as ubiquitous perception system based on spatial big data, online evolution system under complicated transportation environment, smart management and control system with "planning–design–operation–management" to promote the transition of city governance services, achieve the vision of a perceptible, operational, manageable city, promote smart growth of future city and citizens' smart travel, and provide certain experience for smart cities in the future. **DOI:** 10.13813/j.cn11-5141/u.2018.0501-en

Keywords: smart mobility; smart city; big data; perception system; online simulation; decision-making support

In the new era, the revolution of global information technology has advanced by leaps and bounds. The new generation of information technology environment, such as the Internet of Things, Cloud Computing, Big data and Artificial Intelligence, have led to new operation modes and service modes of urban traffic operation, and have made it possible to make smart decisions in the whole chain of urban traffic and to construct the smart city in the new era. The mainstream direction of urban smart transportation development in the future is to serve the intelligent operation and organization of urban and integrated traffic. It is supported by comprehensive perception, ubiquitous connectivity, pervasive computing, integrated applications and artificial intelligence applications to realize the intelligent management and operation of the city and ensure its sustainable development. In recent years, the Party Central Committee, the State Council, and relevant ministries and commissions of China have intensively issued relevant guidance documents to promote the development of smart transportation, providing new opportunities for the development of smart transportation in the new era. The 19th National Congress of the Communist Party of China put forward the strategy of "building China to be a country with a strong transportation network". The State Council promotes the "Internet+" initiative and proposes the use of big data analysis to improve the social governance capabilities of governments at all levels. The National Development and Reform Commission and the Ministry of Transport of China have proposed the use of "Internet +" convenient transportation to promote the development of intelligent transportation [1–3]. Driven by emerging information technologies, the future city will be highly intelligent, service-oriented and smart. The development concept and mode of smart transportation will also experience profound changes. They will emphasize the use of future technologies to promote the transformation of urban governance services, so as to achieve the highly-efficient, inclusive and sustainable development of cities.

1 The future city and transportation development trends

1.1 The future city will become a new smart city with service orientation as the core

Since the industrial civilization, cities experienced digitization and informatization, and have gradually entered the era of highly intelligent smart city 3.0, namely the new smart city era with service orientation as the core (see Figure 1). The development of smart cities has four main characteristics: 1) data Collection. Instead of focusing on data collection and information acquisition, new smart cities focus on data processing to provide higher value-added information services. 2) Information analysis. New smart cities

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emphasize cognitive intelligence and implement intelligent decision-making based on fast computing and information perception. 3) Urban construction participants. The construction of smart cities has evolved from government-led development to government-enterprise cooperation and multi-agent collaborative participation, in order to meet the needs of multiple groups for diverse services. 4). Functional application. The era of new smart cities focuses on application integration based on users' service needs.

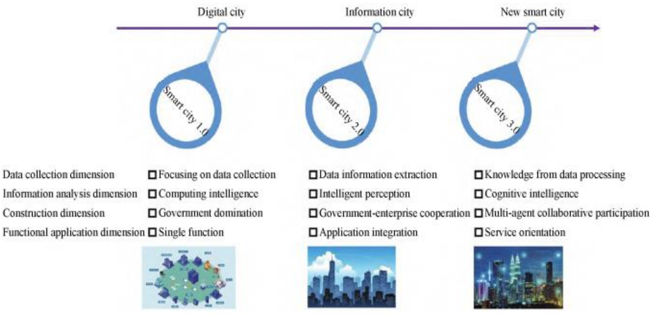

Figure 1 Future urban evolution trend

1.2 Future transportation will provide new smart transportation services based on demand

It is widely accepted by international authorities that urban traffic will undergo subversive changes in the next 15 to 30 years. McKinsey & Company believes that transportation will show seven major trends in the next 15 years: the popularization of shared mobility, automotive electrification, autonomous driving, new public transportation, renewable energy, new infrastructure, and Internet of Things [4]. The future travel mode will rely on the big data perception of the Internet of Everything, supported by a new generation of transportation infrastructure and transportation vehicles, to provide a new type of on-demand transportation service [4]. The US *Emerging Technology Trends Report 2016–2045* predicts the transportation-related emerging technologies in the next 30 years. Technologies such as Internet of Things, Clean Energy, Data Mining, Blockchain, and Quantum Computing will realign traditional transportation modes. We are at the forefront of the fourth technological revolution [5].

2 Key features of the future city and transportation

The innovation of the new generation of information technology provides a steady stream of power to the future city, and promotes a comprehensive transportation system which is safe, convenient, efficient, green and economical. The future city and transportation system will be based on the Internet of Everything and ubiquitous perception, and provide sustainable mobility services with smart city governance and human behaviors as the cores. They have four key features as described below.

1) In the future, complex transportation giant systems require the construction of an interconnected, diversified and multi-dimensional system with big data ubiquitous perception. The innovative integration and rapid development of physical technology, digital technology and biotechnology provide the foundation for realizing the interconnection of everything in a city. The future transportation system will develop into a complex giant system integrating multi-source sensing, machine vision, computer network and other technologies. the larger system indicates the more complex operational structure, the more diverse needs, and the broader scope. As an important foundation for urban development, digitalization and informatization need to strengthen the wireless communication and sensing system to build a new generation of information-aware environment, realize the comprehensive perception, efficient transmission and intelligent control of intelligent transportation systems, and build a big data ubiquitous perception system that meets the needs of future cities and transportation systems (see Figure 2).

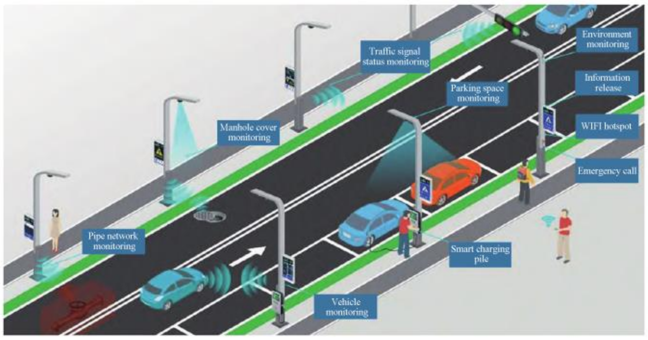

Figure 2 Perception ecology of future city and smart street

2) The future city will focus more on governance rather than management. It emphasizes government service transformation, service synergy and creating social value, and urban development will highlight smart governance and smart growth. The future urban governance system will integrate the urban strategic system, spatial planning system, public policy system, intelligent transportation support system and governance mechanism system. It will pay more attention to the precise control of traffic demand, the smart control of traffic management and the individuality of transportation services, in order to seek breakthroughs in urban governance and improve the level of smart governance in the future.

3) Future transportation focuses on sustainable mobility with more emphasis on serving people's travel needs and multi-party participation. The future city will shift from paying attention to the traffic capacity to improving the accessibility, fairness and sustainability of travel, paying more attention to the integration of various travel modes and the improvement of travel environment. Public demands are increasingly valued by the government and the service industry. By uniting stakeholders such as traffic planners,

transportation operators and citizens, they can participate in the sustainable mobility planning in a comprehensive and transparent manner, thereby building an efficient, fair and healthy urban transportation environment and building a livable urban ecosystem (see Table 1).

Table 1 Comparison of conventional transportation planning and mobility planning

Project	Traditional transport planning	Sustainable urban mobility planning
Focus of planning	Traffic	Human activities and trips
Objectives of planning	Improve traffic flow capability and speed	Improve accessibility and quality of life, as well as sustainability, economic viability social equity, health and environmental quality
Thought of planning	Modal-focused	Coordinate all relevant transport modes and shift towards cleaner and more sustainable transport modes
Compilation of planning	Domain of traffic engineers planned by experts	Regular monitoring and evaluation of impacts to inform a structured learning and improvement process
Evaluation and adjustment of planning effect	Limited impact assessment	Interdisciplinary planning teams and planning with the involvement of stakeholders using a transparent and participator approach

Source: Reference [6]

4) Future travel services focus more on the multi-modal, networked, and collaborative operational structure, providing users with integrated travel services during entire trips that can meet individual needs and focuses on customer experience. The goal of the future transportation is to provide customized services to meet the individual needs of travelers. It develops service plans that meet the actual needs, provides differentiated and diversified full-process services, optimizes travel chains, and serves travelers with high-quality and efficient services.

The four aspects mentioned above are also the cores of smart transportation in developed countries in Europe and America. In the smart city system of Europe and America, smart transportation is a key component, whose core is mainly reflected in the construction of four major systems (see Table 2). The four systems are smart perception (such as smart roads), smart decision-making (such as smart logistics, smart parking, and customized shipping), smart operations (such as smart traffic control) and smart services (full-chain personalized services, such as smart connections, customized information, and Robot picking up), which represent the inevitable direction of the future smart transportation [7].

3 Establishment of a “4C” smart mobility framework

The future city will become highly intelligent. It emphasizes using technology to enhance governance and services, and to create an efficient, inclusive and sustainable city. The future city will be a city that is perceptible, operable, manageable and serviceable (see Figure 3). The core is to utilize smart mobility and future technologies to create a ubiquitous perception city, a real-time deduction city, a smart managing city, and an all-aspect serving city, “4C” for short.

Table 2 Key points of smart mobility in European and American smart city system

Index	US			Europe		
	New York	Chicago	San Francisco	Amsterdam	London	Florence
Smart parking	√	√	√	√	√	√
Smart connection	√	√	√	√	√	
Customized traffic information	√	√	√	√	√	√
Smart traffic light control system	√	√	√	√	√	
Car with adaptive communication connection	√		√			
Shared autonomous car	√		√	√	√	√
Smart road lamp	√	√	√	√	√	√
Location information service of iBeacon		√	√	√	√	√
Customized freight	√	√	√	√	√	√
Robot picking up	√	√	√		√	
Smart logistics	√	√	√	√	√	√

Source: Reference [7].

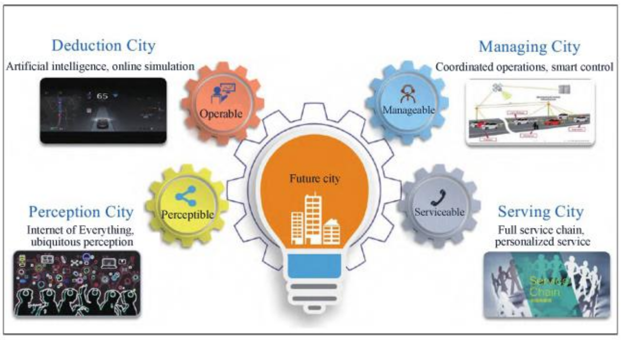

Figure 3 Architecture of 4C smart mobility solutions for future city

3.1 Establishment of a ubiquitous perception system based on spatial big data

Data is the foundation of urban construction, management and development, and the data perception system is shifting from “passive construction and lack of hierarchy” to “deep sensing and ubiquitous perception”. Facing the needs of the future complex and massive mobility system, front-end infrastructure should emphasize standardized deployment, multi-source sensing and smart analysis, and all mobility-related social and economic elements should be digitized, including the flow of people, goods, vehicles, finance, as well as infrastructure, city operations and natural environment. The temporal and spatial trajectories of all these elements need to be fully tracked, and a new generation of smart road sensing framework should be created that can cover all participants at all times and locations and at all resolutions (see Figure 4).

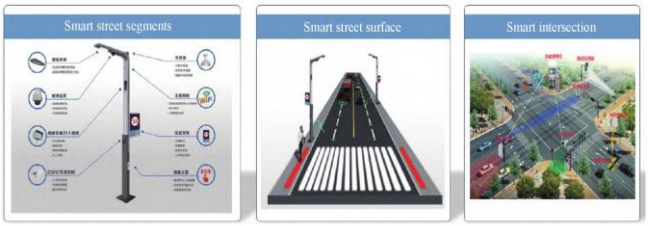

Figure 4 A new generation of smart road perception ecosystem

1) Perception of all participants means perceiving the status of people, vehicles, and streets as well as traffic flows and environmental conditions, and establishing a ubiquitous transportation perception system of "people–vehicle–street–traffic flow–urban environment".

2) Perception at all times and locations means tracking and analyzing the changing traffic trends and the entire life-cycle of infrastructure in depth. The goal is to support infrastructure planning, design, construction, hand-over, monitoring, and maintenance, to create an all-aspect, continuous temporal and spatial monitoring framework, and to fully grasp the development trends of the city and transportation system.

3) Perception at all resolutions means collecting data at multiple levels from macro-to-meso-to-micro and at all resolutions, such as coil-, geomagnetic-, and checkpoint-based data at intersections, microwave-, video-, and mega-range-radar-based data from road segments, and video-, microwave-, and cell-phone-signal-based pedestrian and traffic data for the entire network. The data can be used to precisely describe and depict different events, behaviors and characteristics within the mobility system.

Under this new perception framework, the future city will take smart streets as the basic unit, fully coordinate front-end infrastructure, conduct distributed data collection and processing, and establish a smart street perception monitoring system that includes smart street segment, smart street surface, and smart intersection.

1) The smart street segment, based on intelligent streetlights, collects and integrates data to provide a comprehensive perception service. It integrates multiple functions, such as smart monitoring, traffic flow detection, road hazard identification, vehicle-street coordination, and traffic information dissemination into one system, thus achieving ubiquitous perceptions.

2) The smart street surface, based on smart street stickers that are installed on street markings or shoulders, builds in functions including locating, monitoring, informing and ad-hoc network into one system. It integrates advanced micro-sensing technology, micro-power processing technology and low-power wireless communication technology to achieve applications such as traffic data monitoring, vehicle trajectory tracking, pedestrian cross warning, and vehicle safety warning. It also coordinates with smart streetlights to achieve comprehensive monitoring.

3) The smart intersection, based on smart traffic signals, proactively integrates street infrastructure from different operators. Through edge computing in the front-end and integrated management in the back-end, it achieves transit signal priority, smart operation monitoring and smart infrastructure operation and maintenance with smart intersections as the basic units.

3.2 Establishment of a real-time deduction system to replicate and infer traffic scenarios under complex conditions

Based on Artificial Intelligence (AI) and machine-learning, the real-time traffic conditions are replicated in the brain of urban transportation, and the traffic conditions are deduced and predicted in real time. The "perception–prediction–management–service–perception" self-learning closed-circuit is achieved, and the mobility management framework of "strategic planning–tactical simulation–precise adjustment" is reshaped. These are not only the technological requirements for detail-oriented traffic management and control, but also the critical conditions for establishing an efficient, safe, and coordinated smart urban mobility environment.

1) Based on the online simulation model, deduct traffic conditions under complex situations in real time

The real-time online traffic deduction system is used to comprehensively grasp traffic operations at the macro district level as well as traffic flow conditions at the micro corridor and node level. Based on real-time traffic flow data, vehicle-based location data, and internet-based data, traffic operations are simulated in real-time. The short-term traffic flow trends are predicted, and the causes and impacts of traffic congestions are analyzed. This will achieve regional traffic control coordination and balance traffic flows, as well as provide precise control or prevention tactics for traffic warnings and guidance, optimization of traffic signal timing, evaluation and selection of action plan, and micro traffic enhancements. As a result, the traffic control and decision-making levels are improved to achieve the efficient and orderly operation of the streets. Shenzhen has completed the real-time online simulation platform for Futian CBD, which has proved to be crucial in regional traffic control and balancing traffic flows. This system will be expanded to the entire city, acting as the brain of urban transportation to fully control the mobility system and rapidly respond to events (see Figure 5).

Figure 5 Real-time traffic deduction platform in Shenzhen

2) Based on the real-time simulation of traffic accidents, reduce the negative impact of various traffic incidents (accidents)

Through real-time online deduction, in the event of a traffic accident, a traffic emergency response plan is generated in real time, and the emergency personnel is deployed rapidly and intelligently to minimize the negative impact caused by the accident. For example, in the Niujue Overpass traffic accident on Nanping Expressway in Shenzhen, the precise police deployment and the vehicle rerouting guidance based on the real-time deduction platform guided vehicles to avoid the crash site efficiently, and the accident was cleared in 15 min. The efficiency of accident handling has doubled since traffic congestion would continue for over 30 min prior to the operation of this system.

3.3 Establishment of a smart management system for "planning–design–operation–management" of transportation

To meet the increasingly complicated demand on urban mobility management in the new era, the urban mobility management system is transitioning from fragmented and passive demand response to matching supply and demand and overall management. Using mobility big data as the new engine of the urban mobility smart growth model involving "planning–design–operation–management", the government planning, construction, and management processes are further rebuilt and improved.

1) Build a mobility big data system to support the planning, construction, and decision-making of the future city

Based on the big data system of mobility, which is a planning, construction, and decision-making support platform, multivariate data analyses can be conducted to provide scientific decision-making support for development of transportation strategy, infrastructure decisions, comprehensive management and assessment of environmental safety. For instance, to support the population analysis of the Shenzhen City Master Plan, population data, mobile phone data, building survey data, water and electricity usage data, waste output data and other related data are integrated and analyzed together to understand the actual population size that the city needs to manage, as well as its distribution and growth trend. The results show that the actual population size of Shenzhen is increasing, and the periphery region increases at a faster rate.

2) Realize mobility fine design based on big data spatial activity analysis and simulation technology

The first is to realize the transition from the traditional OD analysis to the analysis on residents' activity space. To achieve this transition, an overall fine design process of mobility needs to be built, including multi-source data collection, identification of demand features, and implementation of mobility design details. For example, in the street design and landscape improvement project of Futian Central District, drones are used to monitor streets. The videos shot with drones, which together with the shared bike transaction data and the street monitoring data, are used to analyze the main street pedestrian volumes, pedestrian activities and durations, and shared bike usage time and parking characteristics. The analyses are then used to make more specific improvements on sidewalks, bike lanes, street functions, street shops, and street landscape. The second is to use data model and traffic simulation technology to simulate the traffic flow and the operation of transportation infrastructure such as hubs, railway stations, and streets. It helps the comparison and optimization of design alternatives and reduces the cost waste of unreasonable constructions and renovations.

3) Establish smart road operations for the future Internet of Vehicles (IoV) and autonomous cars

The first is to realize the transformation of the management model on infrastructure, organization, and the city level management, based on the city's macro transportation management and control strategy. The designs, and operation and organization model of future streets need to be studied in advance, such as narrower but more efficient lanes and more space for non-motorized traffic flow. The second is to accelerate the development of national and local autonomous driving test standards, and to promote the establishment of urban-level autonomous driving solutions including autonomous organization model of driving and operating, infrastructure construction, autonomous vehicle selection, autonomous driving control centers and regulatory standards. These solutions will help explore a beneficial path for the future construction of smart cities. The third is to establish a vehicle-road coordination control center for all complex environments, and to realize the intelligent dispatch of autonomous vehicles based on the city-level online deduction platform. The resource library of autonomous vehicle dispatching strategy should be established by building the autonomous driving algorithm pool including intelligent dispatch of each autonomous car, cluster organization and scheduling of multiple autonomous cars, dynamic path planning, and automatic parking, etc. Based on online traffic simulation technology, vehicle dispatching strategies are deduced in real time, and the dispatching effects are evaluated to realize the zero intervention, zero operation and intelligent dispatching of autonomous cars under multiple scenarios.

4) Build a smart control system to optimize the allocation of all time and space resources for the future road transportation

With the goal of comprehensively improving the allocation of all time and space resources for the future road transportation, the future urban traffic smart management and control system will be constructed at four levels, namely the regional, urban, corridor, and node levels. At the regional level, a customized management and control program that can meet diverse needs should be developed based on Internet + big data technology and under the guidance of the regional macro-control strategy. For example, some states in the United States have implemented a full-process guidance and reward mechanism based on the Metropia mobile application, which has changed the travel plans of 20% of travelers during peak hours (Figure 6). At the urban level, using traffic traceability technology, a smart road management and control platform for the coordinated operation of the whole road network should be constructed. For example, Shenzhen integrates mobile phone signaling data, taxi OD and other data to analyze the total travel demand and trip routing, and builds a city-wide traffic traceability platform to assist in formulating strategies to regulate travels across regions and along key corridors. It guides travel demands from peak hours to off-peak hours and from high demand routes to low demand routes, so as to achieve regional temporal and spatial balance. At the corridor level, based on real-time interaction and location-aware technology, signal priority for special vehicles and public transportation should be implemented in all scenarios, including under different transit flows, different control modes, different traffic saturations and different road conditions. In the meantime, the function to collaboratively control people, vehicles and roads should be reserved in the future Internet of Vehicles environment. At the node level, based on the characteristics of a city and its transportation, the nodes' time and space resources should be balanced through detailed service innovations such as reversible lanes, turning left using opposite lanes, zipper merge, and intelligent signal timing. It adapts to temporal and spatial changes of specific traffic demands, and helps realize the fine management and control as well as the exploration of detailed service innovations.

3.4 Establishment of an integrated and personalized full-chain smart mobility service system

Mobility as a Service (MaaS) is the mainstream trend of urban transportation services in the future. By integrating various transportation modes into a unified service system and platform, the integration of information, operation and payment is realized, and the social resource allocation is optimized to provide users with an integrated and personalized full-chain smart mobility service (see Figure 7).

Figure 6 Application of active travel demand management based on Metropia App

Source: Metropia App.

1) MaaS provides efficient, green and smart travel services based on a powerful travel planning system

MaaS is guided by the traveler experience, with the goal of minimizing preparation time, waiting time, response time and status switching time. It provides sharing, integration, service and guidance. Sharing requires the full sharing of various traffic data. Integration means various transportation modes are highly integrated, based on the idea of proactive traffic demand management to regulate traffic demand. It also means the integration of payment systems. Service indicates providing seamless connection, and safe, convenient and comfortable full-chain travel services. Guidance implies expanding the shares of green travels and promoting public transportation.

2) The government, market, enterprise and citizen collaborate and jointly participate in the construction of full-process mobility service.

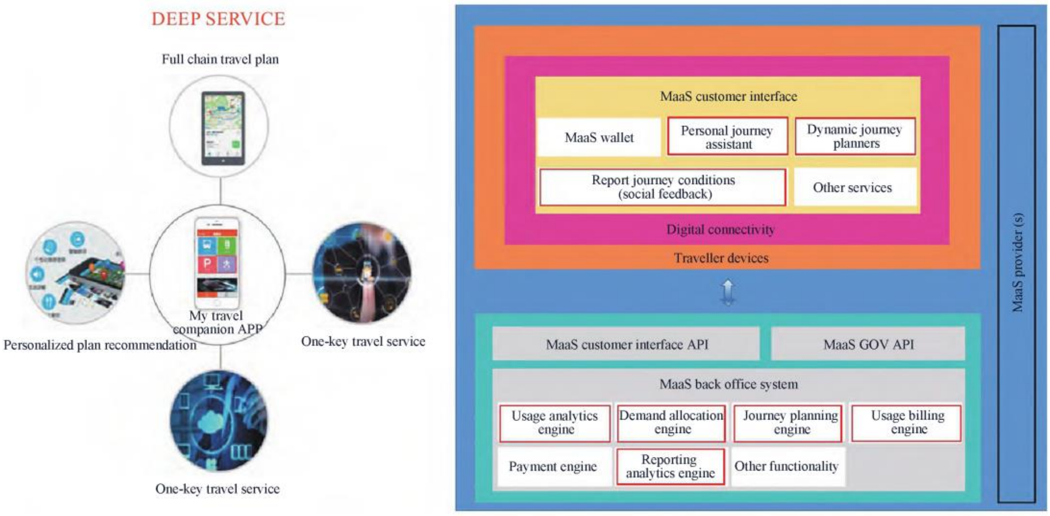

Figure 7 Smart travel solution based on MaaS

Source: Exploring the Opportunity for Mobility as a Service in the UK. Transport Systems Catapult.

The basic data of various travel modes and the massive dynamic information should be comprehensively integrated. The original government-led traffic planning, construction, and operation management mode should be replaced by a new mode that is jointly built by the government, market, enterprise and citizen. For example, Finland piloted the MaaS service in the European Union. Guided by the government, MaaS Global, the world's first MaaS operator, developed a mobile application called Whim to allow users to book multimodal travel services (see Figure 8).

Figure 8 Whim APP for multimodal MaaS services in Finland

Source: Whim APP.

4 Conclusion

This paper is aimed at the new smart city era with service as the core orientation. Based on the development trend of advanced smart cities in Europe and the United States, this paper proposes a new generation of integrated smart mobility solutions and implementation paths around four systems including the smart mobility perception system, decision-making system, management and control system, and service system. This paper proposes to build a ubiquitous perception city, real-time deduction city, smart managing city, and all-aspect serving city. It will help promote the transformation of the operation organization model and service model of urban transportation in the future, and provide guidance on urban smart management and operation services in the new era.

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