Consideration on Construction and Development of Shanghai Smart Metro

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ABSTRACT
The degree of intelligence and service level of urban rail transit has significant influence on the measurement of intelligent transportation. In this paper, the importance of smart metro development is discussed from the perspectives of national development background, technology development trends, and people’s basic requirements, and the features of smart metro in multiple levels are analyzed. On this basis, the construction target, system architecture, and construction methods of smart metro are put forward, and the applications of smart metro are elaborated from smart construction, smart operation and maintenance, and smart service.

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With the rapid development of new generation communication and computer technologies such as 5G, block chain, and artificial intelligence, mankind has ushered in the fifth industrial revolution, which has also added wings to the development of smart metro. In recent years, the smart applications of urban rail transit in China have been in the process of continuous exploration and innovation. The applications such as barcode scanning, face recognition, and internet ticketing have brought passengers a new ride experience while improving the quality and efficiency of operation management and maintenance management.

Shanghai Metro actively promotes the construction of “Smart Metro” in the transformation and development, and actively adapts to new development trends such as the scale of urban rail transit engineering construction, diversified financing methods, networked line layout, diversified transportation systems, intelligent operation methods, and support technology informatization, realizes resource integration, model innovation, and efficiency optimization, so that the service level can be further improved and the rapid development of Shanghai’s urban rail transit can be boosted.

1. Development background

1.1. Construction of transportation power

In September 2019, the Central Committee of the Communist Party of China and the State Council issued the notice of “Outline for the construction of a powerful transportation country”, requesting to further emancipate the mind, forge ahead, promote the transportation development from the pursuit of speed and scale to a greater emphasis on quality and efficiency and from relying on traditional factors to paying more attention to innovation driven transformation, build a safe, convenient, efficient, green, and economical modern comprehensive transportation system, create first-class facilities, first-class technology, first-class management, and first-class service, and build a powerful transportation country with satisfactory people, strong security, and world leading.

Innovation is the first driving force for development and the strategic support for building a modern economic system. The state requires that we aim at the frontiers of world science and technology, strengthening basic research, and achieving major breakthroughs in forward-looking basic research.
and leading original achievements. Therefore, strengthening applied basic research, expanding the implementation of major national science and technology projects, and highlighting the innovations of key common technologies, frontier leading technologies, modern engineering technologies, and disruptive technology can provide strong supports for building a strong country with advanced science and technology, high quality, foremost aerospace, vigorous network, powerful transportation, great digital power, and smart society.

Therefore, the implementation of technological innovation is a major strategy for the next stage development of China. As the core force of transportation in large cities, in order to cooperate with the vigorous promotion and support of technological innovation at the national level, rail transit can bring new development through intelligent and smart innovative applications.

1.2. Support smart city construction

Smart city is the new trend of urban development under “Internet+”. Smart transportation is an important component of a smart city. It can improve the efficiency of resource utilization while greatly improving the transportation efficiency, ensuring the traffic safety, and improving the transportation environment. The outline of the national medium-and long-term science and technology development plan puts forward the following requirements for transportation intelligence:

“taking smooth and convenient人性化 transportation services as the core, strengthening overall planning, developing the information and intelligent technology for transportation system and the transportation technology with safety and high-speed, improving the capacity and efficiency of the transportation network, realizing the sharing of traffic information and the effective connection of various transportation modes, improving the technical level of transportation operation management, and developing comprehensive transportation (Gu, Huang & Hu, 2016, p. 1).”

Smart metro construction is the guiding project of smart transportation construction and smart city construction, it is the main starting point for high-quality development of urban rail transit and a vital way for independent innovation and development of the rail transit industry. Rail transit plays an increasingly important role in urban transportation. The degree of intelligence and service will directly affect the ability of smart transportation. Therefore, the construction and innovation of smart subways should be vigorously promoted from the perspective of supporting smart cities and smart transportation.

1.3. Operation status of Shanghai Metro

Shanghai has the largest urban rail transit network in China. As shown in figure 1, by the end of 2019, the total length of Shanghai urban rail transit network operation lines had reached 705 km (including 29 km of maglev), the number of stations had increased to 415, and the number of transfer stations had increased to 57. In 2019, the scale of Shanghai’s urban rail transit line network ranked first in the world at 801.3 km, there were 3.88 billion passengers throughout the year, and the number ranked third in the world.

With the continuous expansion and extension of the urban rail transit network, the pressure of passenger flow has gradually increased. The proportion of public transport trips in Shanghai’s urban rail transit has continued to increase from 5% in 2000 to more than 66.6% at the end of 2019 (excluding taxi trips). At present, the average daily passenger flow of Shanghai’s urban rail transit network has exceeded 10 million passengers. On March 8, 2019, the highest daily passenger flow reached 13.294 million passengers. Rail transit has become the primary choice for Shanghai residents and tourists.

In recent years, the construction and commissioning of projects in succession, e.g., fully automatic operation, code sweeping, construction management platform based on the building information model (BIM), Shanghai Rail Transit Network Operation Command and Control Building, and Shanghai Rail Transit Industry Data Center, provide a new way for Shanghai rail transit ultra-large-scale network operation management (Yu, 2018). Shanghai urban rail transit needs to seize the development opportunities of smart cities, develop smart metro well, and maintain the industry’s first-mover advantage through quality leadership under the framework of smart cities and smart transportation.
2. Connotation of smart metro

Smart metro has received great attention from the rail transportation industry. In the continuous exploration and practice of smart metro, the industry has gradually improved its comprehensive knowledge of smart metro. Smart metro aims at ensuring the overall safety, improving the transportation efficiency, polishing up the operating efficiency, and improving the service quality. It adopts emerging information technologies such as the Internet of Things, 5G, cloud computing, big data, block chain, and artificial intelligence to enhance the capabilities of holographic perception, real-time analysis, scientific decision-making, and precise execution to create a metro transportation and service system with intelligent allocation of construction, operation and maintenance, service resources, and intelligent business linkage.

After years of research and practice, Shanghai Metro has summarized and refined “SMART” to annotate the basic characteristics of smart metro.

(1) S: state perception

Through the application of intelligent sensing technologies such as intelligent sensing and video analysis, it can actively sense and discover various types of objects such as facilities, environments, passenger flows, and workers in the entire life cycle of rail transit.

(2) M: data management

All kinds of data such as real-time data, static data, and business execution data in rail transit are aggregated, and then extracted, cleaned, and loaded to realize the digitalization of smart metro business.

(3) A: automatic analysis

The applications of means such as big data intelligent analysis and decision-making technology, multi-source heterogeneous data fusion, and equipment health diagnosis to the in-depth analysis and mining of metro operation data provide scientific decision-making basis for metro construction, operation, maintenance, etc.

(4) R: round business

With the big data intelligent analysis and diagnosis results, the collaborative automation, process visualization, business standardization of various types of rail transit transactional operations and management can be achieved.

(5) T: tenacious evolution:

In the early stage, software such as expert system is used to achieve functions such as automatic diagnosis and smart work orders. With the accumulation of data, cases, etc., self-learning and self-evolution are carried out with artificial intelligence technology, and the intelligent level of smart metro is continuously improved.
As shown in figure 2, smart metro is a gradual process. It develops from object digitization to implementation intelligence, and finally to the ultimate realization of decision-making and linkage intelligence. Smart metro is not a newly built system, but a process of intelligently empowering the existing metro business through the research, development, and introduction of new technologies in other fields, in combination with the business characteristics and scenarios of metro, so that finally the improvement of the service quality and execution capabilities of various businesses can be realized.

Figure 2. Development process and characteristics of Shanghai smart metro.

3. Construction object of smart metro

In order to meet the high-quality development requirements of the new era, the development needs of Shanghai as a global excellent city, and the requirements of construction and operation for the ultra-large urban rail transit network, Shanghai Metro starts from the business pain points and needs under the operation of ultra-large network, and takes the four dimensions of “safety, service, efficiency, benefit” as the construction goals of smart metro. Under the wave of scientific and technological innovation in China, various new technologies and breakthroughs are constantly emerging.

However, the construction of smart metro should not be smart for “smart”, all kinds of smart pilot applications and construction must be under the four dimensions of “safety, service, efficiency, benefit”, and the construction needs of various applications should be objectively assessed. On this basis, the integration of informatization and automation technology, the construction of intelligent perception and intelligent linkage, and the execution promotion of metro businesses driven by data support the sustainable development of Shanghai subway network.

3.1. Improvement of safety and reliability

The primary goal of metro operation is safety. Metro operation should ensure the safety of passenger rides, trains, and facilities and equipment while ensuring the punctual operation of the trains. Based on the technologies such as Internet of Things equipment, video surveillance, mobile applications, and remote monitoring, the safety warning, civilized construction, abnormal behavior monitoring, safety inspection, etc. on the construction site are achieved. Through the state perception of all kinds of equipment, the operation safety and reliability of the key operating facilities and equipment such as trains and stations are improved with the big data technology, and the transformation of facilities and equipment from fault repair to state repair is realized.

The operating environment of rail transit is monitored, and disasters are avoided by monitoring the real-time environment of various computer rooms through the Internet of Things technology. The real-time early warning and trend judgment of local disaster weather for elevated station is realized. The safety of personnel in the subway space is globally monitored, and the working status of personnel in key positions such as train drivers is judged. Through the construction of video models and face recognition database, the abnormal behaviors of passengers are monitored and alarmed globally. The rapid positioning and handling of emergencies and the early perception of large passenger flow are realized to ensure the travel safety of the majority of passengers and the safety of subway operations.

3.2. Improvement of service level

Passengers are the main part of metro services. With a huge underground space, metro is not only a place for passengers to take transportation but also a place
for people to live and entertain themselves. Through the construction of smart metro, it is possible to realize and improve the differentiated and comprehensive travel experiences of different people based on the travel chain. Through intelligent detection technology, passengers can realize passive and non-sensory security screening. Through the application of smart vision and the establishment of station inspection business can be realized through manpower and working time, while the whole status inspection business of the traditional configuration of customer service personnel in the station. The inspection business of the traditional module, traditional automatic ticket buying improved. The combination of voice recognition efficiency and effectiveness of metro business operation automation are realized, and the execution flow, the station operation status visualization and perception of various field devices and passenger rooms, bases, etc. Through the real-time status perception of various field devices and passenger flow, the station operation status visualization and operation automation are realized, and the execution efficiency and effectiveness of metro business are improved. The combination of voice recognition module, traditional automatic ticket buying machine, and intelligent inquiry robot can reduce the configuration of customer service personnel in the station. The inspection business of the traditional station work area often requires a certain amount of manpower and working time, while the whole process monitoring and the data collection of the station inspection business can be realized through the development of mobile applications and the use of intelligent terminals. Through the combination of video analysis, artificial intelligence, and robot technology, the staff can be completely replaced by a special inspection robot, and thus the efficiency of production operations is improved.

3.4. Improvement of economic efficiency

Urban rail transit is facing huge investment pressure during the large-scale construction stage, and it is also facing huge financial pressure during the operation and maintenance of the completed urban rail transit lines. In terms of facility equipment management, Internet of Things technology can be used to achieve intelligent storage of facility equipment and reduce labor costs; and the emerging technologies such as Internet+, big data analysis, and artificial intelligence can be used to improve the availability of facility equipment throughout its life cycle, reduce the facility equipment failure rate, and optimize the life cycle of spare parts.

In terms of operational efficiency, big data analysis and artificial intelligence can be combined to optimize the work such as driver scheduling and automatic train entry and exit operations; intelligent frequency conversion can be used in the environmental control system to dynamically adjust the environment during the operation of stations and trains to save energy and reduce the consumption; and big data technology can be used to establish a complete index system for business segments such as rail transit construction, operation and maintenance, and services, and effectively control costs and investments through data analysis.

In addition, while enhancing production efficiency and passenger service, economic benefits should be fully considered, and the balance among “efficiency”, “service”, and “benefit” should be ensured as much as possible. It should be objectively assessed that which intelligent applications can improve economic efficiency and which applications are needed to evaluate and measure economic benefits, otherwise it will lead to negative growth of benefits.

4. Structure of Shanghai Smart Metro

4.1. Overall structure

The construction of smart metro should promote the improvement of the overall management capability of Shanghai Metro through the integration of intelligent technology applications at the technical level and the linkage at the business level.

(i) Application of intelligent technology

Application of intelligent technology refers to the application of various intelligent technologies such
as face recognition, image recognition, voice recognition, big data analysis, artificial intelligence, robots, etc. in various business areas of urban rail transit aiming at improving the safety and quality of business execution.

(ii) Business linkage integration

Business linkage integration refers to the realization of data-driven services. The execution status or execution result of a business directly triggers the execution or execution of other services, thereby improving the efficiency and effectiveness of business execution. Typical scenarios include one-click operations for business linkage, etc. Guided by the IT governance concept of “standardized management, orderly advancement, controllable cost, resource sharing”, with the unified standard specification and security policy as the guarantee, Shanghai Metro builds a “1 axis”, “1 cloud”, “3 domains”, “5 layers”, and “X-class” smart metro framework with the architecture of “a metro hub integrated platform, a metro cloud, three smart areas, 5-layer architecture, X-class smart devices”, as shown in Figure 3.

![Figure 3. Technical structure of Shanghai Smart Metro.](image)

The specific means are as follows:

(i) “1 axis” means a metro central system, with which the knowledge accumulation ability of the metro industry can be improved, and the whole picture of smart metro can be comprehensively displayed in an all-round and multi-dimensional way.

(ii) “1 cloud” means a metro cloud, including mass storage and computing platform, data resource platform, IT service platform, etc.

(iii) “3 areas” means three smart areas at the application layer, with which the business execution capabilities can be improved from the three aspects of smart construction, smart operation and maintenance, and smart services.

(iv) “5 layers” means a 5-layer smart metro technology architecture system, including the acquisition layer, the storage layer, the data processing layer, the application layer, and the comprehensive decision-making layer.

(v) “X-class” means X-class intelligent equipment, e.g., inspection equipment, duty equipment, ticket vending equipment, customer service robots, etc.
4.2. Ideas and methods

The construction of “smart metro” should be guided by the goal of intelligentization, and the application of intelligentization should change from “business-driven” of the traditional metro to “data-driven” through the comprehensive analysis, research, and judgment of massive data. Therefore, the construction idea of smart metro should take “data” as the core, under which a five-layer information system of smart metro technology architecture is built through the integration of automation and informatization and the cloud-side collaboration, namely, “acquisition layer, storage layer, data processing layer, application layer, comprehensive decision layer”.

(I) Acquisition layer

A digital and automated technology system is built to complete the business data, consolidate the data foundation, improve the perception capabilities of equipment, people, environment, systems, etc., and recognize the business more accurately and timely. The data acquisition layer should fully consider the data security, real-time capability, and responsiveness of the edge infrastructure and the reliability of network communication.

(II) Storage layer

A smart metro cloud with massive data storage and processing capabilities is built through the comprehensive analysis of big data and artificial intelligence algorithms. In the construction process, a safe and efficient information network architecture (Gu et al., 2016), a software and hardware infrastructure, and a unified operating environment should be considered in the early design to improve the horizontal expansion capability that changes with the iteration update of the business.

(III) Data processing layer

Based on the massive data of smart metro, a scientific big data system is established, and a platform for smart metro big data analysis is built. At the same time, advanced artificial intelligence and machine self-learning general service modules are introduced to achieve management improvement through the self-evolution of the business. The establishment of the data analysis layer should be modularized, modeled, and software-defined to form a closed loop of data-information-knowledge-decision, improve the data-driven capabilities, and form comprehensive research and judgment, multi-service intelligence linkage.

(IV) Application layer

Based on the existing business architecture and application architecture of urban rail transit, a series of new intelligent applications is established through the improvement of functions and smart empowerment of each business application to enhance the capabilities of business execution and services. In the construction of smart applications, it is still necessary to proceed from the goal of smart metro, fully study the improvement of business capabilities and the achievable level of intelligence, and conduct analysis and post-assessment for the corresponding pilots.

(V) Comprehensive decision-making layer

The comprehensive decision-making layer serves the supervision and decision-making of smart metro, can provide intuitive status monitoring, comprehensive information display, operation status evaluation, analysis results, and scientific auxiliary decision-making information for each business sector, and finally reach the digitalization of business status and industry empirical modeling. The comprehensive decision-making layer should have a complete and perfect business status evaluation system and can provide the corresponding decision-making information to form a complete smart metro business closed loop.

5. Practice and achievement

In recent years, Shanghai Metro has successively adopted technologies such as “Internet of Things”, “Big Data”, “Mobile Internet”, and “Artificial Intelligence” in the metro construction, operation and maintenance, and service businesses, has explored a series of innovative pilot applications, and thus has had a deeper understanding in smart metro and formed a smart metro system suitable for Shanghai’s rail transit. Shanghai Smart Metro consists of three major application segments, i.e., smart construction, smart operation and maintenance, and smart service.

5.1. Smart construction

5.1.1. BIM-based full life cycle construction management platform

With the urban rail transit BIM as the core, combined with the business needs of construction management, and using the characteristics of BIM, Shanghai Smart Metro realizes the full life cycle construction management from scheme design, design collaboration, engineering verification, engineering planning and optimization, on-site real-time information management, dynamic investment
control, and equipment information query to maintenance.

5.1.2. Risk management and control by integrating intelligent vision and remote monitoring

A global eye system is established. Through visual and intelligent image analysis methods, the situation on the construction site in real-time can be grasped, the construction personnel can be effectively controlled, and safety warning can be conducted against the abnormal behavior of the personnel. Based on the remote monitoring and status perception of the construction project, the construction risk and quality control system are studied, and the safety protection and engineering quality at the construction site are real-time monitored and analyzed (Liu, 2017).

The civilized construction platform based on mobile applications is used to inspect the safety, manage the quality, and assess the management of the on-site objects such as equipment, personnel, and materials on the construction site, which further improves the safety management and control capabilities and supervision and management efforts on the construction site and the engineering construction efficiency.

5.1.3. Design planning based on multivariate data

In the early stage of the construction project, big data analysis technology is used to integrate the multivariate data such as mobile phone signaling data and external city data in combination with the integration strategy of the Yangtze River Delta and the Shanghai city master plan to design and forecast the station setting type, design plan, transfer design, passenger flow estimation, etc. and provide guidance for the preliminary design and planning of the project.

5.2. Smart operation and maintenance

5.2.1. Smart station operation

Based on the three major business segments of station personnel management, facility equipment management, and passenger transportation management, technologies such as Wi-Fi sniffing, big data analysis, voice recognition, QR code, and video recognition are used to realize a series of intelligent applications such as automatic switching of stations, unmanned station inspection, automatic perception of passenger flow status, automatic triggering and execution of plans, and active push of operational information to further improve the safety level and response capability of the operation management of Shanghai Metro. The smart station will form a new standard for the station operation mode of Shanghai Metro and will be further extended to all stations in the entire metro network.

5.2.2. Self-adaptive driving scheduling

According to the forecast of the peak and valley of passenger flow, combined with vehicle transportation and carrying capacity, the transit capacity is timely and dynamically adjusted, and the efficiency of operation and management is improved. The linkage of passenger transportation and vehicle driving is improved, and the efficient collaboration of operating organization is achieved. The fully automatic operation mode of metro is promoted, and the driving safety is improved.

5.2.3. Crew software scheduling

The crew organization and train driver status evaluation are optimized, the crew task and scheduling are optimized based on the real-time value adjustment of the train, and the crew task matching scheme is optimized. The crew rotation is optimized, and the crew plan is intelligently compiled. The working status of the driver and customer service staff is adjusted in real-time through intelligent visual analysis to guarantee the operation safety and service level.

5.2.4 Smart city linkage

Data sharing and real-time communication are established with Shanghai “Smart City”, the linkage with departments such as public security, fire protection, water affairs, power supply, and communication is formed, and the rational allocation of public resources for city operation is realized, which can ensure the rapid and proper responses in major emergencies.

5.2.5 Online vehicle control

Video analysis technology is used to identify and monitor the status of vehicles entering and leaving the warehouse. The vehicle operating status is monitored in real-time through advanced communication technologies, with which the alarm information and remote disposal support can be provided in time. The vehicle historical data are tracked and mined to provide supports for status repair. In cooperation with mobile inspection system and eagle eye system, the electronic inspection process is realized.

5.2.6 Power supply network remote control

Through the Internet of Things and network communication technologies, the real-time monitoring and remote control of the operation
status of the network power are realized. Video analysis technology is used to monitor and forecast the key parts such as power facilities and power houses in real-time to ensure the safety of the entire metro network.

5.2.7. Work vehicle inspection

By adding on-board sensors and Internet of Things equipment to special vehicles such as rail inspection vehicles and flaw detection vehicles, through the means such as video analysis and big data analysis, continuous tracking and prediction of the track and tunnel status are realized, and faults are quickly located and handled.

5.2.8. Real-time precise monitoring of communication signals

The instructions and service transmission status of the communication system and the communication services in various scenarios are monitored in real-time to accurately locate faults. For information systems, on the basis of deep integration of traditional maintenance monitoring systems and communication-based train control (CBTC) maintenance support systems, the status collection, acquisition, and storage of signal equipment are fully realized. A signal information center for the signal system equipment maintenance is constructed to provide the most accurate and comprehensive data support for fault intelligent diagnosis, early warning analysis, and maintenance and maintenance strategies.

5.2.9 Base intelligent operation

The main business systems such as “maintenance, safety, logistics, environment, life” for the base take automation and informatization as the starting points, and realize the global monitoring and intelligent operation of the vehicle base through the development of the Internet of Things, communication, and information platform.

5.3 Smart service

5.3.1 Passenger autonomous service

The use of technologies such as voice recognition, image recognition, and big data and the introduction of intelligent equipment such as customer service robots and interactive screens provide passengers with information inquiry and review services such as station profiles, station facilities, convenience services, route recommendations, and station navigation. Passenger inbound and outbound means are increased by scanning codes through intelligent mobile terminals, which further promote the interconnection of the QR code of public transportation in the Yangtze River Delta. The introduction of technologies such as biometric recognition and voice analysis and the establishment of voice ticketing machine enrich the ticket purchase methods of automatic ticket inspection system.

5.3.2. Intelligent passenger guidance

Video image acquisition equipment is installed in the station entrance and platform waiting area, and intelligent video analysis technology, train weighing data collection technology, and optimal waiting area algorithm are comprehensively adopted to realize real-time station passenger flow monitoring, early warning, and intelligent ride guidance and provide location-based smart ride guidance service.

5.3.3. Inspection service robot

A service robot with functions such as voice inquiry, station guidance, and automatic inspection is configured. Through human-computer interaction, it provides passengers with comprehensive personality information services such as inquiring station operating time, morning and evening train hours, and location of station service facilities. It can also use machine learning technology to carry out self-learning based on the content of passenger inquiries, and continuously expand its scope of services.

5.3.4 Indoor positioning and navigation applications

A variety of Internet of Things technologies such as low energy Bluetooth and Wi-Fi are used to provide indoor positioning and navigation services in the underground space of the station. These services fully cover the public areas of the station and face passengers and special passengers (visually impaired passengers), and provide passengers with personalized guidance services such as autonomous positioning, destination searching, and real-time navigation by using personal mobile terminals through APPs, and thus a new type of service experience is achieved.

6. Conclusions

Smart metro can provide passengers with new and convenient travel experiences such as optimal travel planning, smart ticketing services, interactive information query, and business-life interfaces. Meanwhile, it can provide technical support for intelligent metro operations to achieve comprehensive operation and maintenance management such as passenger flow early warning, driving scheduling, fault maintenance, and safety guarantee. Through the construction of smart metro, operation managers can greatly improve the
efficiency and quality of rail transit business execution, while effectively control the costs and provide personalized convenience and services for passenger travel. In the future, the integration of multiple emerging technologies and the intelligent development of urban rail transit with multiple advantages will better enhance the social and economic benefits of urban rail transit and support the construction of smart city.

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