IX. Engineering Management

1 Engineering research fronts

1.1 Trends in top 10 engineering research fronts

In the field of engineering management, this year's top 10 global engineering research fronts are "medical material supply and allocation under magnitude outburst public health incident," "supply chain resilience," "social responsibility for major projects," "urban flood risk management under extreme rainfall conditions in the future," "cooperative driving control and management," "project management based on blockchain," "industrial intelligence based on big data," "cascading failure simulation of urban lifeline system and toughness coupling analysis technology," "electric vehicle charging infrastructure layout and optimization," and "simulation optimization under artificial intelligence background". The core papers are shown in Tables 1.1.1 and 1.1.2. Among them, "medical material supply and allocation under magnitude outburst public health incident," "supply chain resilience," and "social responsibility for major projects" will be interpreted with emphasis, and the current development status and future trends will be interpreted in detail later.

(1) Medical material supply and allocation under magnitude outburst public health incident

Medical materials refer to the general term of materials provided by the society to the health department and the public in order to provide medical services under certain social and economic conditions. The key medical materials in dealing with magnitude outburst public health incidents include: 1) medical protective materials, such as masks and protective clothing; 2) medical drugs; 3) medical treatment equipment, such as respirators. The supply and allocation of medical materials refers to the reserve, procurement, donation, and shift and expanded production of medical materials in a planned way, accurately matching supply and demand, and distributing medical materials fairly and efficiently based on scientific demand forecast of medical materials. In response to magnitude outburst public health incidents such as SARS, Ebola virus, and COVID-19 pandemic, the demand for medical materials has surged, and it is time-sensitive and irreplaceable, which brings great challenges to the supply and allocation of medical materials. In response

Table 1.1.1 Top 10 engineering research fronts in engineering management

No.	Engineering research front	Core papers	Citations	Citations per paper	Mean year
1	Medical material supply and allocation under magnitude outburst public health incident	10	133	13.30	2016.6
2	Supply chain resilience	33	963	29.18	2017.6
3	Social responsibility for major projects	34	643	18.91	2017.4
4	Urban flood risk management under extreme rainfall conditions in the future	10	1 146	114.60	2016.7
5	Cooperative driving control and management	44	1 265	28.75	2016.9
6	Project management based on blockchain	27	2 835	105.00	2018.1
7	Industrial intelligence based on big data	52	5 322	102.34	2017.6
8	Cascading failure simulation of urban lifeline system and toughness coupling analysis technology	17	120	7.06	2016.6
9	Electric vehicle charging infrastructure layout and optimization	51	3 089	60.56	2017.1
10	Simulation optimization under artificial intelligence background	17	195	11.47	2017.5

Table 1.1.2 Annual number of core papers published for the top 10 engineering research fronts in engineering management

No.	Engineering research front	2014	2015	2016	2017	2018	2019
1	Medical material supply and allocation under magnitude outburst public health incident	1	0	5	2	0	2
2	Supply chain resilience	2	0	4	6	11	10
3	Social responsibility for major projects	0	3	4	11	9	7
4	Urban flood risk management under extreme rainfall conditions in the future	1	0	2	5	2	0
5	Cooperative driving control and management	4	2	9	13	10	6
6	Project management based on blockchain	0	0	3	3	9	12
7	Industrial intelligence based on big data	0	0	7	16	21	8
8	Cascading failure simulation of urban lifeline system and toughness coupling analysis technology	3	1	6	0	4	3
9	Electric vehicle charging infrastructure layout and optimization	5	4	9	6	15	12
10	Simulation optimization under artificial intelligence background	1	1	1	3	7	4

to the COVID-19 epidemic, many countries have experienced “shortage of medical materials.” Therefore, the United Nations initiated an initiative to guarantee the supply of medical materials, the European Commission decided to build a shared strategic inventory of medical equipment, and the United States launched the *Defense Production Act* (DPA). Medical material support directly affects the overall situation of dealing with magnitude outburst public health incident. Key scientific issues, such as accurate prediction of medical material demand, supply mode according to local conditions, matching between supply and demand, and fair and efficient distribution mechanism, are the international frontier topics and hotspots of emergency management, psychology and industrial engineering.

(2) Supply chain resilience

In the current political, economic, and natural environment, the supply chain is facing more and more sudden risks, such as terrorism, economic blockade, earthquakes, and hurricanes. These risks can easily lead to the interruption of the supply chain and affect the continuous operation of projects or enterprises. Different from traditional supply chain risks, it is difficult for us to predict the occurrence probability and impact of unexpected risks in advance through statistical data. Many unexpected risks are even “unknowns,” so the traditional risk management framework of “risk identification—risk evaluation—risk response—risk monitoring” is difficult to adapt to sudden risks. In this context, a resilient supply chain has become an important tool to deal with sudden risks, which makes the research on supply chain resilience increasingly important. Supply chain resilience emphasizes the ability to return to its original state or a more ideal state after being disturbed by sudden risks. In the existing research on supply chain resilience, key scientific issues, for example how to effectively measure and evaluate supply chain resilience, and how to improve supply chain resilience, are the research hotspots of civil engineering and industrial engineering. At the same time, the endogenous decision-making problem of supply chain resilience, the choice of strategies for improving supply chain resilience, and the research on supply chain resilience in specific situations (such as infrastructure operation or aerospace and other specific engineering situations) are possible research directions in the future.

(3) Social responsibility for major projects

Major infrastructure projects (referred to as major projects) are large-scale public projects that have an important impact on national politics, economy, society, scientific and technological development, environmental protection, public health, national security, etc. They have huge investment scale, long implementation period, complex uncertain factors, numerous stakeholders, and far-reaching impact on the ecological environment. With the openness of major projects, diversification of subjects, and the complexity of projects caused by the application of new technologies, the social responsibility management of major projects is facing unprecedented challenges, mainly including the lack of social responsibility of participating subjects, weak awareness of ecological and environmental protection in project construction, and imperfect health and safety system of construction workers. Social responsibility for major projects refers to the social responsibility undertaken by various stakeholders for the impact of their decisions and activities on society and environment in different stages of the whole life cycle of projects, such as planning, design, construction, and operation. At present, the academic circles have made fruitful explorations, but there is still a lack of systematic research. The strategic management system with the sustainability of major projects as the goal and social responsibility as the important support has not yet been established, which is difficult to provide theoretical support and practical guidance for the management practice of major projects. Especially facing the new trend of internationalization of major projects, under the background of political, economic, regulatory, and cultural differences, the conflicts of demands of different stakeholders will also lead to a series of brand-new topics in the research on the management theory and governance system of social responsibility for major projects. It can be seen that the key scientific issues such as the theory, method and modernization of governance system, and governance capacity of social responsibility for major projects will become research hotspots in this field.

(4) Urban flood risk management under extreme rainfall conditions in the future

Urban flood refers to the phenomenon that urban areas are flooded and waterlogged due to heavy rain, torrential rain, or continuous rainfall, and its risk is generally measured by the probability of urban flood and its consequences, such as casualties, infrastructure damage, and environmental damage. Climate change leads to the increase of global temperature and extreme precipitation. Urban expansion increases the impervious area of the region, significantly changes the urban water cycle process, and leads to the increase of surface runoff coefficient and frequent urban floods. Meanwhile, cities are densely populated areas with concentrated productivity and wealth, which can easily cause heavy casualties and property losses. In addition, since the city is a complex open system, flood disasters will have a chain reaction within and between systems, which is more likely to induce secondary and derivative disasters and form a disaster chain, thus further expanding the potential risks of urban flood disasters. Facing the extreme rainfall trend in the future, many countries put forward the urban flood prevention and control system and risk management system according to local conditions, so as to alleviate the negative impact of urban floods on people’s life safety, property, social order, and economy. How to assess urban flood risk under extreme rainfall conditions in the future and improve urban flood prevention and control ability has become a key scientific problem to be solved urgently at home and abroad. With the development of big data and artificial intelligence technology, the integration paradigm of “data-driven” and “model-driven” provides a new idea and technical basis for revealing the mechanism of urban flood disaster, developing the real-time monitoring and early warning and forecasting technology of urban flood based on multi-source data fusion, researching and developing the whole scene simulation platform of urban flood risk, and constructing the coordinated comprehensive prevention and control system of flood control project scheduling and social disaster reduction.

(5) Cooperative driving control and management

Cooperative driving refers to coordinating the trajectory and motion control of multiple vehicles with the support of internet of vehicles and automatic driving technology, so as to make the vehicles run more smoothly and quickly, improve traffic safety and efficiency, and reduce travel time, energy consumption, and pollution. Compared with the traditional traffic control strategies, such as traffic congestion vehicle guidance, traffic congestion pricing, and traffic signal control, cooperative driving deals with the problems of overall traffic management and local vehicle control together, and is thus considered as the fundamental solution to the ground traffic problem. In recent years, new advances in artificial intelligence, big data, and intelligent network connection have provided feasible technical support and research means for in-depth study of cooperative driving. These technologies have greatly changed the means, content, and scope of information acquisition and interaction among traffic participants, vehicles, and road infrastructure, which will promote the whole-process collaborative planning and comprehensive collaborative control of traffic, and then lead to deep changes in traffic safety guarantee, road intelligent management, and efficient travel services, making traffic safer and travel smoother. At present, the key issues of cooperative driving research are collection and fusion of dynamic traffic information in full time and space, collaborative safety and active control of vehicles, cooperative driving under mixed driving of people and vehicles, integration and collaboration of intelligent traffic management and services under panoramic traffic information environment, etc. Studying cooperative driving can greatly improve the perception and decision-making ability of unmanned vehicles, and at the same time, it will provide application scenarios for high-tech such as 5G communication and cloud computing, and provide theoretical basis and decision support for further upgrading and development of transportation systems.

(6) Project management based on blockchain

All kinds of projects, including infrastructure construction, aerospace, water conservancy and water transport, and energy development, have jointly promoted China's economic and social development and played an important role in enhancing China's comprehensive strength and improving people's livelihood. Engineering projects usually have the characteristics of large amount of investment, long project cycle, and many participants. The complex cooperation relationship and low level of mutual trust in the project will easily lead to the inconsistency of objectives among participants, weaken productivity, even breed crimes, and hinder the realization of project management objectives. Building trust relationship has become the key to improve project performance and achieve management objectives. Blockchain technology has the characteristics of information tamper-proof, traceability, openness and transparency, automatic execution, etc. It has the potential to change the interaction mode within the organization of engineering projects, and provides the possibility to create a cooperative environment of mutual trust. It has become an important content of strategic information infrastructure in many countries.

Blockchain technology helps to clarify the responsibilities and rights of all participants in the project, reduce the fluke mind and speculative behavior, and promote deep cooperation. The integration of intelligent contract can realize the automation of various businesses including project supply chain collaboration, project data protection, project digital asset transfer, project insurance, project payment, and project human resources and performance appraisal, thus simplifying management logic and reducing management costs. At present, the research on blockchain in the field of engineering management is booming, but it is still in its infancy, lacking empirical exploration, and its potential in engineering bidding, engineering design, engineering implementation, engineering operation and maintenance, engineering supply chain and other aspects is worth studying. In addition, the exploration and verification of the integration of blockchain technology with communication network infrastructure such as 5G, Internet of Things, and Industrial Internet, new technology infrastructure such as artificial intelligence and cloud computing, and computing power infrastructure such as data center and intelligent computing center will help the project management shift to high standard, high efficiency, and high quality paradigm.

(7) Industrial intelligence based on big data

Industrial intelligence is to bring together industry technology, control technology and information technology, so that the process of dynamic operation, management, and service of production has the intelligent ability of perception, memory, learning, self-adaptation, and self-decision similar to human beings. Data is not only the storage form of information in industrial process, but also the carrier of decision and control orders. In recent years, with the improvement of information technology, big data processing technologies, such as data collection, data storage, data analysis and data visualization, have been continuously improved. Therefore, industrial big data can be better collected, sorted, and analyzed, and can better serve industrial management decision-making, operation optimization, and process control. Industrial intelligence based on big data means to realize the intelligent ability of self-perception, self-learning, self-adaptation, and self-decision of industrial process by means of big data processing based on industrial process data such as data parsing, blockchain, and cloud platform. Its main contents include industrial process intelligent perception under the Internet of Things environment, industrial big data storage and management based on cloud platform, industrial big data statistics and analysis, and whole process collaborative optimization and control. In the past decade, the blueprint for industrial intelligence development including Germany's "Industry 4.0" has been widely valued by governments and industries in various countries. With the continuous improvement of big data technology, how to realize the continuous improvement of industrial intelligence level by combining the production environment of different industries, the customization requirements of technological processes, and the stable and efficient means of big data storage and analysis will become the frontier research focus of academia and industry.

(8) Cascading failure simulation of urban lifeline system and toughness coupling analysis technology

Lifeline engineering system refers to the basic engineering system that maintains modern city functions and regional economy, including transportation, water supply, power supply, gas supply, and communication systems. Compared with a single building or bridge structure, lifeline engineering as a system has the characteristics of extensive spatial distribution, complex structural composition, and complex coupling between systems. In recent ten years, the global urbanization process has led to the rapid expansion of city scale, and the complexity and coupling relationship of urban lifeline system have been significantly enhanced, which makes the resilience quantitative model of lifeline system, especially the simulation model of cascading failure and coupling recovery between lifeline systems under different disaster conditions and its efficient algorithm, become a hot issue in current research. On this basis, the resilience quantitative model of urban built environment including lifeline system has been derived, and its practical exploration in different fields such as urban design, planning, reconstruction, and disaster management has been carried out. One of the visible research frontiers in this field in the future is intelligent orientation, that is, by means of advanced technologies in computer communication fields such as artificial intelligence, big data, and 5G network, an efficient and accurate analysis method and intelligent management mode of urban lifeline system toughness are developed. In addition, because the city itself is an ecosystem with highly complex characteristics, it is an inevitable trend to cross-integrate lifeline resilience research with urban social, economic, and environmental disciplines, and it is expected to further promote the development of multi-dimensional (physical, environmental, social, economic, organizational, etc.), multi-scale (streets, districts, cities, urban agglomerations, etc.), and multi-stage (before, during, and after disasters) comprehensive resilience simulation technology, so that the influence of comprehensive quantification, analysis, and management of disasters on the urban built environment, human settlements, social function, regional economy, and even globalization becomes possible.

(9) Electric vehicle charging infrastructure layout and optimization

Charging infrastructure refers to all kinds of charging and replacing facilities that supply electric energy for electric vehicles, including power infrastructure as well as control and communication infrastructure. According to the characteristics of service objects, it can be divided into charging infrastructure in public service field, user's residence and unit charging infrastructure, urban public charging network, and intercity fast charging network. With the rapid development of electric vehicle industry, the planning and construction of charging facilities have entered a large-scale and networked era. How to scientifically and systematically optimize the layout of charging infrastructure is particularly important. A perfect charging infrastructure system is an important guarantee for the popularization of electric vehicles, the rational allocation of power resources, and the reduction of greenhouse gas emissions. Technical characteristics of electric vehicles, behavior characteristics of service objects, different business models, and electricity price, and load of power grid will directly affect the layout and optimization decision of charging infrastructure. In addition, emerging technologies, including wireless power transmission, connected mobility, autonomous driving, sharing mode and energy internet, will bring technical changes to future electric vehicle applications. Electric vehicles, can be used not only as transportation tools, but also as a node of power loads (G2V), distributed energy storage (V2G) of power grids, energy storage (V2B) of buildings, and network communication. Optimization issues such as location and scale layout of charging infrastructure, timing of investment and construction, charging and discharging scheduling of electric vehicles, integration of charging facilities and smart grid, and construction of intelligent charging service platform are the international frontier research hotspots of urban planning, traffic engineering, management science, and electrical engineering.

(10) Simulation optimization under artificial intelligence background

Artificial intelligence is a technical science that studies how to simulate and extend human intelligence through computers, including key technologies such as machine learning and system simulation. In recent years, machine learning technology has been widely used in society, such as driverless cars and product recommendation of shopping software. System simulation describes the operation, evolution, and development process of the system through simulation model, which is one of the key technologies of artificial intelligence. Under the background of Industry 4.0, more and more intelligent systems have applied machine learning technology, which puts forward higher requirements for system simulation. In developing the corresponding simulation model, it is necessary not only to integrate the machine learning module, but also to spend more energy to calibrate and optimize the complex simulation model. On one hand, researchers can not only apply simulation data to neural network training, but also directly apply simulation models to deep reinforcement learning, thus improving the accuracy of machine learning technology; on the other hand, machine learning and intelligent sampling methods can speed up the calibration and optimization of simulation models. Under the background of the rise of digital twins, how to improve the simulation efficiency of high-fidelity simulation model by using machine learning method has become an international research hotspot. The main research directions include studying the simulation optimization theory and method aiming at improving the quality of machine learning algorithms, exploring how to improve the accuracy and operational efficiency of the simulation model by machine learning, and realizing the real-time optimization decision of digital twin model by using offline simulation, real-time simulation, and machine learning methods.

1.2 Interpretations for three key engineering research fronts

1.2.1 Medical material supply and allocation under magnitude outburst public health incident

In economics, "supply" refers to the products and quantities that producers will and can supply at a given price within a specific time. "Allocation" refers to allocating an appropriate amount of materials to the appropriate demanders according to the demand information. In 1979, Professor Ilhan and Professor Pierskalla of Turkey first studied the blood supply and allocation between major hospitals. Subsequently, they studied the disaster types that the medical materials were supplied and allocated to, including earthquakes, hurricanes, and SARS, aiming to meet the demand for medical materials. The supply and allocation of medical materials are the core and key to improve the level and ability to deal with magnitude outburst public health incident, and they are also the premises to further improve the national emergency management system and realize the modernization of the national governance system and governance capacity.

The following part is a more in-depth analysis of the demand forecast, supply mode, supply-demand matching, and allocation mode of medical materials; and the development trend of medical materials supply and allocation is prospected.

(1) Demand forecast of medical materials

Demand forecast of medical materials refers to the forecasting of the demand of certain medical materials by collecting and analyzing relevant data and selecting appropriate forecasting methods in order to identify the quantity of materials needed by medical institutions and the public in providing or receiving medical and health services. Accurate demand forecast of medical material is the basis of good medical material supply and allocation. Generally, the demand forecast of medical materials aims at identifying the demand of inpatient or outpatient service. Moving average and linear regression methods are usually used to forecast the daily demand of medical resources such as beds, medical staff, and blood in medical institutions, and the demand fluctuation is often small. However, for the epidemic situation of major infectious diseases, the demand for medical supplies such as protective equipment and first aid equipment is determined by the severity of the epidemic situation, and the demand will fluctuate with the development of the epidemic situation. Under the background of COVID-19 epidemic, the demand forecast of medical material considering the evolution of epidemic situation is the mainstream of research. Scholars have put forward various forecasting indexes and corresponding forecasting methods. The research hotspots of medical material demand forecast mainly include the demand forecast of medical material considering the coupling relationship between medical material supply and epidemic evolution, and based on the correlation of epidemic transmission among regions.

(2) Supply mode of medical materials

Under the magnitude outburst public health incident, the government-led diversified supply mode of medical materials has achieved remarkable results in the prevention and control of COVID-19 epidemic in China, including four major supply modes of reserve, social donation, market procurement, and shift and expanded production. Shift and expanded production of medical materials means that the government encourages and guides social enterprises to switch to and expand the production of medical materials through mobilization mechanism, and uniformly allocates the materials to meet the needs of medical institutions and the public for medical materials. Shift and expanded production is the guarantee of medical material supply in the prevention and control of COVID-19 epidemic in China, which was also adopted by other countries like the United States and Canada. For example, Ford, General Motors, and Tesla in the United States switched to the production of respirators, Canadian beer giant Labatt switched to produce disinfectant, and Canada Goose switched to produce protective clothing urgently needed by front-line medical staff. In order to support the shift and expanded production of medical materials, the corresponding countries have given a series of policies, such as providing venues and financial support, reducing taxes or providing subsidies. In the case of dynamic evolution of epidemic situation, the capacity design of shift and expanded production of medical materials should be dynamically optimized in multiple stages. In the supply mode of medical materials, the research hotspots of capacity design mainly include mobilization mechanism of shift and expanded production of medical materials, evolutionary game model between medical institutions and the public, enterprises for shift and expanded production and government, and dynamic optimization mechanism of medical material price control, tax incentives, and financial subsidies under the evolution of epidemic situation.

(3) Supply and demand matching of medical materials

For the supply of medical materials donated by the society, the key is to effectively match the information of supply and demand of medical materials and solve the problem of information asymmetry between supply and demand sides. Social donation is a voluntary donation made by the people or units in order to rescue disasters, relieve poverty, help the disabled and other difficult social groups and individuals, support scientific, educational, cultural, and health undertakings, and environmental protection, and build social public facilities. Internet platform has become the main carrier of matching supply and demand of social donated medical materials. Under the Internet platform, the core of matching the supply and demand of social donated medical materials is to realize the identification and automatic matching of supply and demand information by using information processing technology. Social media, as the medium of post-disaster supply and demand information release, is the source of post-disaster supply and demand information data. Many scholars consider material types and geographical factors, and use relevant information processing methods to study the effective matching of social donation materials information and demand information on social media. The research hotspots of medical material supply and demand matching mainly include the design of medical material supply and demand matching index under the Internet platform, the establishment of dynamic interactive model of medical material supply and demand matching under uncertain conditions, and the development of data processing technology for obtaining and matching medical material supply and demand information.

(4) Allocation mode of medical materials

The allocation mode of medical materials refers to the allocation strategy and scheme of medical materials. In the response to magnitude outburst public health incidents, the allocation of medical resources is often coupled with the ability of medical treatment and the evolution of events. On one hand, the allocation of medical materials will affect the ability of receiving and treating and the efficiency of treatment, and then affect the evolution of the whole epidemic situation; on the other hand, the evolution of the epidemic situation will in turn affect the strategies and schemes for the distribution of scarce materials. Current research discusses the coupling relationship between medical materials and the spread and evolution of infectious diseases from different angles. In the process of dealing with large-scale infectious diseases, graded treatment is the key measure to avoid the spread of diseases and to facilitate the rational allocation of scarce materials. Current research mainly focuses on the grading criteria for individual patients and the principle of providing them with scarce medical resources, mainly considering the principle of fairness and the goal of minimizing casualty rate. From the level of scientific research and medical practice, the medical community has explored the guiding principle of grading patients according to the use of some specific key medical equipment from a more detailed level, so as to improve the survival rate when a large-scale epidemic occurs. The research hotspots of medical material allocation mode mainly include the mutual influence law between medical material allocation and epidemic evolution, and the dynamic allocation mechanism of medical materials under the graded treatment mode.

(5) Development status and future development trend

The United States Naval Medical Research Unit has studied the algorithms for effectively predicting the types, quantities, and configurations of medical materials, and developed the Estimating Supplies Program to improve the supply and management level of medical materials. In response to the COVID-19 outbreak, the World Health Organization has set up a working group to implement the United Nations initiative to ensure the supply of medical materials, and plans to establish a global material supply platform to accept applications for material supply from countries in need, purchase materials centrally, and distribute materials according to the urgency of demand. In 2020, the National Natural Science Foundation of China launched the special project “Response, Governance, and Impact of Public Health Events such as COVID-19 pandemic,” in which the mode of medical resources supply and allocation under magnitude outburst public health incidents is the key funding direction. Based on the current research status, the future development trends mainly include modeling and verification of the coupling law between medical material supply, allocation, and epidemic evolution, combination optimization among different medical material supply modes under the dynamic evolution of epidemic situation, and optimization of medical material allocation under the Internet environment.

Two countries with the most core papers in the engineering research front of “medical material supply and allocation under magnitude outburst public health incident” are China and the United States (Table 1.2.1). China mainly focuses on impact assessment of public health events and the risk management of the allocation of emergency materials, while the United States focuses on the distribution of the last kilometer of emergency supplies. The number of documents in Germany, Brazil, India, and the United Kingdom is equal, studying the allocation of emergency and non-emergency medical service resources, the emergency supply of medical personnel, the matching of supply and demand of medical resources based on multimedia information mining, and demand prediction and analysis of medical resources, respectively. There is no cooperative relationship between these countries.

Beijing Normal University ranks first in the number of core papers, which mainly studies the risk prediction of contamination in material transportation. Other institutions have the same number of core papers (Table 1.2.2). According to the cooperation network diagram of core paper producing institutions (Figure 1.2.1), among the top 10 institutions in the number of core papers publishment, University of Sao Paulo, Universidade Federal Fluminense, Brazilian Ministry of Health, and Inter-Union Department of Statistics and Socio-Economic Studies (DIEESE) have more cooperation.

According to Table 1.2.3, China ranks first in citing core paper. According to Table 1.2.4, the top institutions are North China Electric Power University, Chinese Academy of Science, Wright State University, and Beijing Normal University .

1.2.2 Supply chain resilience

The concept of “supply chain resilience” was first proposed by Professor Rice and Professor Caniato in 2003, but its definition was first proposed by Professor Christopher and Professor Peck in 2004, who defined supply chain resilience as “the ability of the supply chain to return to its original state or a more ideal state after being disturbed.” As scholars realize that resilient supply chain is an important tool to deal with sudden risks, the research on supply chain resilience has gradually increased. The following part mainly analyzes the theoretical research perspective, research methods, hot research issues, measurement and evaluation, and improvement of supply chain resilience.

(1) The theoretical research perspective of supply chain resilience

In the study of supply chain resilience, scholars have adopted more than 20 kinds of theories, including macro theory, meso theory, and micro theory. Among these theories, the most commonly used theories are resource-based view, dynamic capability theory, relationship theory, and system theory/complex adaptive system theory, among which resource-based view is the most basic and core theory. The resource-based view of the firm regards enterprise as a collection of a series of resources. The ability and competitive advantage of enterprises originate from the valuable, scarce, unrepeatable, and irreplaceable resources owned by enterprises. Under the complex and changeable environmental disturbance, enterprises need to continuously integrate, construct, and reconfigure internal and external resources, so as to enhance the supply chain resilience. However, because the resource-

Table 1.2.1 Countries with the greatest output of core papers on "medical material supply and allocation under magnitude outburst public health incident"

No.	Country	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	China	3	30%	56	18.67	2016.0
2	USA	3	30%	37	12.33	2015.7
3	Germany	1	10%	20	20.00	2017.0
4	Brazil	1	10%	14	14.00	2016.0
5	India	1	10%	4	4.00	2019.0
6	UK	1	10%	2	2.00	2019.0

Table 1.2.2 Institutions with the greatest output of core papers on "medical material supply and allocation under magnitude outburst public health incident"

No.	Institution	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	Beijing Normal University	2	20%	50	25	2016
2	Wright State University	1	10%	29	29	2014
3	Charite	1	10%	20	20	2017
4	DIEESE	1	10%	14	14	2016
5	Brazilian Ministry of Health	1	10%	14	14	2016
6	Universidade Federal Fluminense	1	10%	14	14	2016
7	University of Sao Paulo	1	10%	14	14	2016
8	Xi'an Jiaotong University	1	10%	6	6	2016
9	U.S. Department of Health and Human Services	1	10%	4	4	2016
10	Emory University Hospital	1	10%	4	4	2016

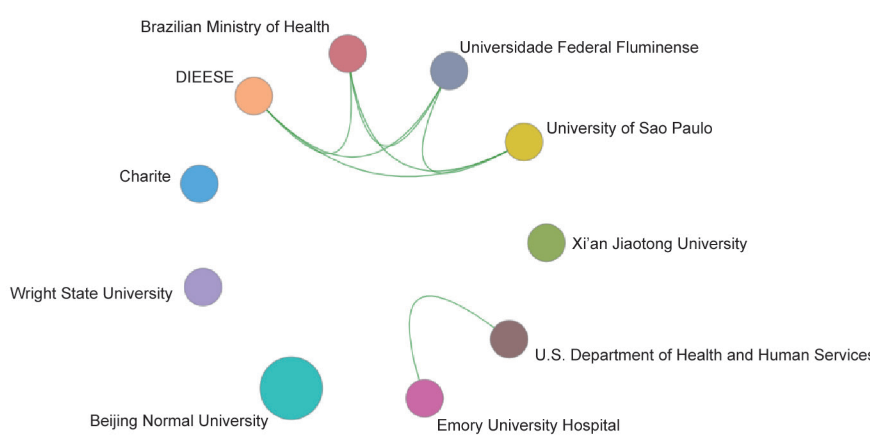

Figure 1.2.1 Collaboration network among major institutions in the engineering research front of "medical material supply and allocation under magnitude outburst public health incident"

based view is static in nature, ignoring the influence of market dynamics, scholars have adopted dynamic capability theory and relationship theory to expand the resource-based view under the dynamic environment. In addition, some scholars believe that the supply chain is a complex system, and that resilience is an inherent feature of the system, so they adopted

Table 1.2.3 Countries with the greatest output of citing papers on "research on medical material supply and allocation under magnitude outburst public health incident"

No.	Country	Citing papers	Percentage of citing papers	Mean year
1	China	39	27.27%	2018.3
2	USA	32	22.38%	2018.3
3	Germany	23	16.08%	2017.9
4	Brazil	16	11.19%	2018.4
5	Australia	9	6.29%	2018.7
6	Canada	6	4.20%	2019.0
7	UK	5	3.50%	2018.8
8	Iran	4	2.80%	2018.5
9	Belgium	3	2.10%	2017.0
10	India	3	2.10%	2018.7

Table 1.2.4 Institutions with the greatest output of citing papers on "research on medical material supply and allocation under magnitude outburst public health incident"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	North China Electric Power University	7	14.58%	2018.3
2	Chinese Academy of Sciences	6	12.50%	2017.8
3	Wright State University	5	10.42%	2016.8
4	Beijing Normal University	5	10.42%	2017.8
5	Tianjin University	4	8.33%	2017.8
6	University of Tehran	4	8.33%	2018.5
7	Wuhan University	4	8.33%	2019.5
8	Charite- Medical University of Berlin	4	8.33%	2018.5
9	China Institute of Water Resources and Hydropower Research	3	6.25%	2019.0
10	Pan American Health Organization	3	6.25%	2018.7

system theory/complex adaptive system theory to study the supply chain resilience.

(2) Research methods of supply chain resilience

The research methods of supply chain resilience can be divided into qualitative research methods and quantitative research methods. Among them, qualitative research methods are mainly case studies, while quantitative research methods mainly include optimization, decision analysis, network modeling, and simulation. Optimization is the most frequently used quantitative research method, including multi-objective linear programming, stochastic programming, and objective programming. The main methods used in decision analysis are multi-objective decision analysis, analytic hierarchy process, and network analysis. The methods of network modeling include Bayesian network, graphic modeling, and clustering supply chain network model. The simulation methods include agent-based simulation and discrete event simulation.

(3) Hot research issues of supply chain resilience

When the supply chain resilience was put forward in the early days, scholars paid more attention to the definition and connotation of supply chain resilience. With the deepening of research, scholars focus on the measurement and evaluation of supply chain resilience, and the improvement of supply chain resilience.

(4) Measurement and evaluation of supply chain resilience

Although scholars have different definitions of supply chain resilience, they have a strong consensus on the connotation and essence of supply chain resilience, that is, they think that supply chain resilience refers to the ability to return to the original state or a more ideal state after being disturbed, but scholars use different methods to measure and evaluate the supply chain resilience. At present, the existing methods for measuring and evaluating supply chain resilience can be divided into four categories. 1) Measuring the resilience with core elements. The supply chain resilience is decomposed into several core elements, and these core elements are scored by questionnaire. The most common core elements include flexibility, redundancy, and agility. 2) Using direct quantitative indicators to measure the resilience. The quantitative indicators used in this kind of method include the time required for the supply chain to return to its original or more ideal state after being disturbed, the degree of recovery, and the degree of loss of supply chain performance during the recovery period. 3) Measuring the resilience with specific quantitative indicators of supply chain performance evaluation. Scholars use one or more supply chain performance evaluation indicators, such as customer service level and order satisfaction rate, and evaluate the resilience through simulation and other methods. 4) Using topological index to measure the resilience. This kind of indicators mainly measure resilience from the perspective of complex networks, and commonly used indicators include density, complexity, node criticality, and average path length.

(5) Improvement of supply chain resilience

The main purpose of studying supply chain resilience is to improve the supply chain resilience and establish a resilient supply chain. Therefore, scholars have given a series of strategies on how to improve the supply chain resilience. These strategies can be divided into two categories: One is the active strategy before interruption and the other is the passive strategy after interruption. The active strategy before interruption refers to the measures that can resist interruption, such as improving the flexibility of product, contract, and procurement to improve the resilience of supply chain before interruption; promoting the information sharing and cooperation of all participants in the supply chain through the integration of supply chain, so as to resist the possibility of interruption; enhancing the supply chain resilience through business diversification and financial services such as insurance in the case of strong financial strength. Passive strategy after interruption refers to the measures that can still maintain certain basic functions and quickly restore normal functions after interruption. The main promotion strategies are response strategies, such as setting up emergency response teams and responding quickly to market demands, and recovery strategies, such as making contingency plans after interruption, building the ability to absorb losses, and considering the improvement of supply chain resilience by optimizing recovery costs.

As an important tool of supply chain risk management, the supply chain resilience has been widely studied by scholars, but there are still some problems to be solved urgently.

First, the endogenous decision-making research of supply chain resilience. Enhancing supply chain resilience plays an important role in dealing with unexpected risks, but it usually comes at the expense of the overall efficiency of the supply chain, that is, a stronger supply chain usually means lower supply chain efficiency. Although scholars have done a lot of research on supply chain resilience, these researches basically assume that supply chain resilience is exogenous, so how to make decisions on the strength of supply chain resilience is the first problem to be solved in future research. Second, the research on the choice of strategies for improving the supply chain resilience. Scholars have put forward many strategies on how to improve supply chain resilience, such as increasing supply chain redundancy and enhancing information sharing among supply chain members. Different strategies or combinations of strategies have different effects on enhancing supply chain resilience. How to choose strategies to improve supply chain resilience is also a problem to be solved in future research. Third, the study of supply chain resilience in specific situations. At present, the research on supply chain resilience is usually aimed at the general supply chain, and the conclusions obtained are difficult to be directly applied to specific situations. How to study supply chain resilience by considering the unique characteristics of a specific situation is also one of the future research directions, such as the research on resilience management of overseas infrastructure construction and operational supply chain.

From the published core papers, the top three countries are Germany, France, and the United States (Table 1.2.5), The research priorities of the three countries are different. Germany and France are more inclined to the expansion and development of quantitative research methods for supply chain resilience, while the United States pays more attention to the study of strategies for improving supply chain resilience, especially the active strategy before the interruption occurs. The top three countries in citations per paper are Russia, Germany, and France (Table 1.2.5). As show in the cooperation network diagram of core paper output countries (Figure 1.2.2), Russia, France, and Germany have more cooperation. The top two institutions in the published core papers are Berlin School of Economics and Law and Russian Academy of Sciences (Table 1.2.6). As show in Cooperation network diagram of major institutions, Berlin School of Economics and Law and Russian Academy of Sciences have more cooperation (Figure 1.2.3).

According to Table 1.2.7, USA ranks first in citing core papers. According to Table 1.2.8, the top institutions are Berlin School of Economics and Law, Saint-Petersburg State University of Information Technologies, Mechanics and Optics (ITMO Universitg), and Royal Melbourne Institute of Technology University .

1.2.3 Research on social responsibility for major projects

Major projects have become the lifeline of national economic and social development, and social responsibility has become an important support for the construction and management of major projects. Social responsibility for major projects involves direct participants (government, project contractors,

Table 1.2.5 Countries with the greatest output of core papers on “supply chain resilience”

No.	Country	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	Germany	16	48.48%	597	37.31	2017.6
2	France	13	39.39%	477	36.69	2017.7
3	USA	12	36.36%	287	23.92	2017.8
4	Russia	9	27.27%	397	44.11	2017.2
5	UK	5	15.15%	97	19.40	2018.2
6	Netherlands	3	9.09%	54	18.00	2018.0
7	India	2	6.06%	39	19.50	2017.5
8	Australia	2	6.06%	35	17.50	2018.5
9	Poland	2	6.06%	33	16.50	2018.0
10	South Korea	1	3.03%	27	27.00	2016.0

Figure 1.2.2 Collaboration network among major countries in the engineering research front of “supply chain resilience”

Table 1.2.6 Institutions with the greatest output of core papers on "supply chain resilience"

No.	Institution	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	Berlin School of Economics and Law	15	45.45%	563	37.53	2017.6
2	Russian Academy of Sciences	6	18.18%	293	48.83	2016.8
3	Institus Mines-Telecom Atlantique (IMT Atlantique)	4	12.12%	164	41.00	2018.0
4	French National Centre for Scientific Research (CNRS)	4	12.12%	127	31.75	2018.2
5	ITMO University	3	9.09%	111	37.00	2017.3
6	The University of Oklahoma	2	6.06%	48	24.00	2018.0
7	Erasmus University Rotterdam	2	6.06%	45	22.50	2018.0
8	Michigan State University	2	6.06%	39	19.50	2018.0
9	University of Plymouth	2	6.06%	35	17.50	2018.5
10	University of Southern Mississipi	2	6.06%	34	17.00	2019.0

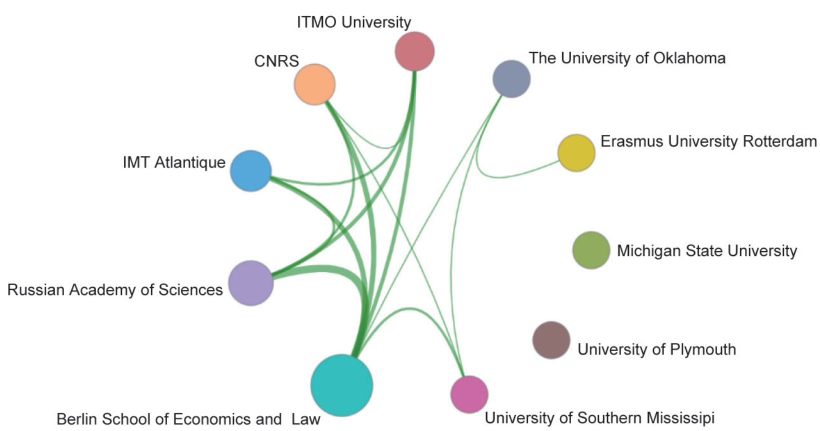

Figure 1.2.3 Collaboration network among major institutions in the engineering research front of "supply chain resilience"

Table 1.2.7 Countries with the greatest output of citing papers on "supply chain resilience"

No.	Country	Citing papers	Percentage of citing papers	Mean year
1	USA	77	18.03%	2018.2
2	Germany	59	13.82%	2018.1
3	China	57	13.35%	2018.2
4	France	47	11.01%	2017.9
5	Russia	35	8.20%	2017.6
6	UK	35	8.20%	2018.4
7	Australia	32	7.49%	2018.2
8	India	30	7.03%	2018.5
9	Iran	28	6.56%	2018.1
10	Canada	15	3.51%	2018.4

Table 1.2.8 Institutions with the greatest output of citing papers on "supply chain resilience"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Berlin School of Economics and Law	41	31.78%	2017.9
2	ITMO University	16	12.41%	2016.5
3	Royal Melbourne Institute of Technology University	13	10.08%	2017.8
4	CNRS	11	8.53%	2018.4
5	IMT Atlantique	9	6.98%	2018.3
6	AGH University of Science and Technology	9	6.98%	2017.3
7	University of Tehran	9	6.98%	2018.0
8	University of Kent	7	5.43%	2018.3
9	Russian Academy of Sciences	7	5.43%	2017.1

suppliers, designers, employees, etc.) and other stakeholders (the public, community, non-governmental organizations, etc.), and the implementation of related activities needs to run through the whole life cycle of major projects. Social responsibility for major projects can be summarized as: all stakeholders of major projects take sustainable development as the goal during the whole life cycle of the project, and take responsibility for the impact of their decisions and activities on society and environment through transparent and ethical behaviors.

(1) Social responsibility and internationalization strategy of major projects

Internationalization of major projects has broken through the traditional construction industry, which requires the organic integration of engineering construction, equipment manufacturing, financial services, consulting services, etc. The promotion of its value chain also needs to transform from construction to construction service integration. Based on this, it is necessary for all participants to consider more dimensions of social responsibility for major projects facing internationalization, including more environmentally friendly construction schemes, more inclusive organization methods, and design schemes that are more in line with the cultural regulations of the host country. At the same time, it is necessary for relevant subjects to push forward from the whole process and all directions, such as realizing environmental sustainability through technological innovation, meeting the employment needs of local labor force through organizational innovation, and promoting local economic development through mechanism innovation. The participants shall promote the social responsibility for major projects, adhere to people-oriented, respect local culture and tradition, ensure the safety and quality of projects and the rights and interests of owners, and take the responsibility from multiple dimensions such as supply chain management and fair competition, so as to actively and effectively lay out the internationalization strategy of major projects. The research issues include the path of multi-dimensional heterogeneity of social responsibility for major projects facing internationalization to the dynamic capabilities of participants, impact of innovation of integration mode of construction services for major projects on social responsibility, social responsibility for major projects, and adaptability of internationalization strategy.

(2) Social responsibility governance system for major projects

The internationalization of major projects in the global pattern can no longer take low cost as its competitive advantage, but needs to be promoted through all-round integration of policy guidance, industry promotion, enterprise implementation, and social participation. Social responsibility for major projects has become an important symbol of major project brands. The governance of social responsibility for major projects requires full participation, not only the construction of industry guidelines, but also the active participation of enterprises and information disclosure. The governance system of social responsibility for major projects needs to be promoted from three dimensions of whole subject, omnibearing, and whole process, covering governance principles, governance logic, and governance paradigm. Related research issues include governance subjects of social responsibility for major projects and their mutual relations, principles of social responsibility governance for major projects and elements of governance capacity, evaluation index system and measurement method of social responsibility governance capacity of major projects, the function path of social responsibility governance capacity of major projects to enhance international competitiveness.

Under the background of the new era, major projects have become an important benchmark of national comprehensive competitiveness, and the urgency and importance of social responsibility governance of major projects have become increasingly prominent. Based on the current research situation and the practical needs of major project management, we can see that the future development trends mainly include the theory and method of social responsibility for major projects facing complex environment and social responsibility governance system for major projects under the international situation.

Judging from the existing research results, the top three countries in the number of core papers in the engineering research front of “social responsibility for major projects” are China, Australia, and the United Kingdom (Table 1.2.9). The top three countries in average citation are Australia, the United States, and China (Table 1.2.9). As show in the core paper output country cooperation network map (Figure 1.2.4), China and Australia have more cooperation. Chinese scholars put forward the topic of social responsibility for major projects firstly. The theoretical framework of social responsibility research for major projects and a three-dimensional dynamic model of “whole life-stakeholders-social responsibility” are established. By relying on the Hong Kong–Zhuhai–Macao Bridge, Guangxi Nanning East Railway Station, Shanghai Maglev and other major projects, the governance framework of major projects for public participation and government participation is put forward. The sustainable effects of major projects in different dimensions, such as economy, environment, and society are revealed. Australian scholars have conducted in-depth research on resource conservation and environmental protection in the social responsibility of major projects. By improving the level of technology and management, the water use efficiency of construction sites is improved, and the generation of waste is eliminated or reduced. Environmental compensation is used to reduce the impact of major projects on the environment. It is proposed to improve the design, approval, evaluation, and supervision process of environmental compensation policies, so as to improve the effectiveness of environmental compensation policies.

The top three institutions in the number of core papers are Hong Kong Polytechnic University, South China University of Technology, and Tongji Univiversity (Table 1.2.10). According to the cooperation network diagram of institutions producing core papers (Figure 1.2.5), among the top 10 institutions in the number of core papers publishment, the University of Hong Kong, South China University of Technology, and Queensland University of Technology have more cooperation. The research team members from the Hong Kong Polytechnic University mainly study the social responsibility issues of major projects from the perspective of stakeholders. They mainly analyze the complexity of stakeholders in major projects and propose to solve the problem of unclear responsibilities in major projects by constructing a framework of stakeholder cooperation, and to balance the rights and corresponding social responsibilities of stakeholders in the project. They put forward the expectation management strategy for stakeholders to pursue the goal of social, environmental, and economic sustainability, which provides support for major engineering practices. The research team members from South China University of Technology and Tongji University analyze the specific behavioral characteristics of social responsibility for major projects from the perspective of stakeholders. They study the specific social responsibility behavior, as well as the motivation and influencing factors of stakeholders’ choice of social responsibility behavior, and put forward the multi-stakeholder multi-objective decision-making method during the period of public participation in major infrastructure projects. The research team members from Shanghai Jiao Tong University focus on the connotation and key elements of social responsibility of major projects, put forward a three-dimensional model of social responsibility of major projects, and construct an index system for evaluating social responsibility of major projects. They put forward the social governance model of social responsibility of major projects and analyze the industry spillover effects of social responsibility of major projects.

According to Table 1.2.11, China ranks first in citing core papers. Meanwhile, according to Table 1.2.12, the top institutions are Hong Kong Polytechnic University and Tongji University.

Table 1.2.9 Countries with the greatest output of core papers on "social responsibility for major projects"

No.	Country	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	China	21	61.76%	489	23.29	2017.5
2	Australia	13	38.24%	430	33.08	2016.9
3	UK	7	20.59%	92	13.14	2017.3
4	USA	6	17.65%	173	28.83	2016.7
5	Netherlands	2	5.88%	25	12.50	2017.5
6	Poland	1	2.94%	14	14.00	2018.0
7	South Korea	1	2.94%	12	12.00	2017.0
8	Malaysia	1	2.94%	2	2.00	2018.0
9	Iran	1	2.94%	0	0.00	2019.0

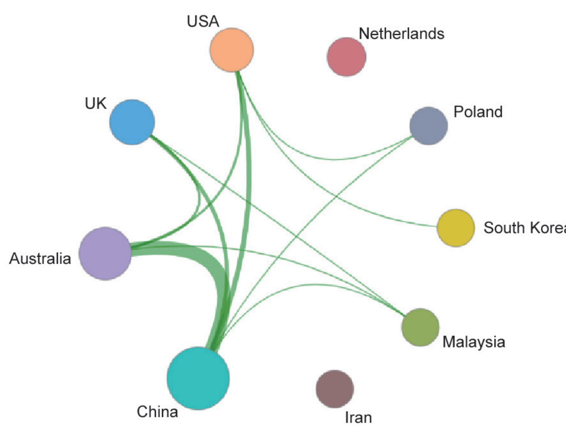

Figure 1.2.4 Collaboration network among major countries in the engineering research front of "social responsibility for major projects"

Table 1.2.10 Institutions with the greatest output of core papers on "social responsibility for major projects"

No.	Institution	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	Hong Kong Polytechnic University	6	17.65%	207	34.50	2017.5
2	South China University of Technology	5	14.71%	75	15.00	2017.8
3	Tongji University	5	14.71%	21	4.20	2018.4
4	Shanghai Jiao Tong University	4	11.76%	150	37.50	2016.8
5	The University of Hong Kong	4	11.76%	74	18.50	2017.5
6	Queensland University of Technology	4	11.76%	44	11.00	2017.8
7	Royal Melbourne Institute of Technology University	3	8.82%	194	64.67	2016.3
8	Nanjing Audit University	3	8.82%	72	24.00	2017.3
9	University of Florida	2	5.88%	104	52.00	2016.0
10	University of South Australia	2	5.88%	54	27.00	2015.5

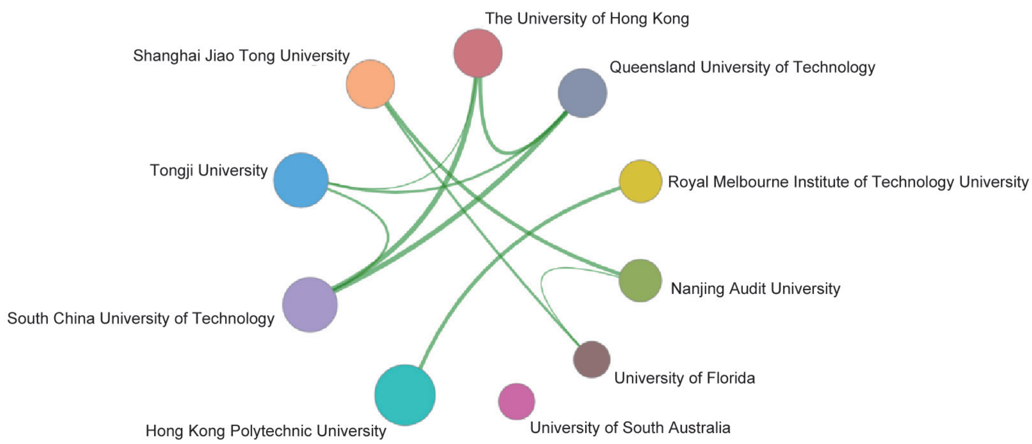

Figure 1.2.5 Collaboration network among major institutions in the engineering research front of "social responsibility for major projects"

Table 1.2.11 Countries with the greatest output of citing papers on "social responsibility for major projects"

No.	Country	Citing papers	Percentage of citing papers	Mean year
1	China	210	40.08%	2018.4
2	Australia	93	17.75%	2018.4
3	UK	66	12.60%	2018.5
4	USA	49	9.35%	2018.6
5	Netherlands	30	5.73%	2018.3
6	Iran	18	3.44%	2018.3
7	Malaysia	15	2.86%	2017.7
8	Spain	14	2.67%	2018.2
9	South Africa	10	1.91%	2018.8
10	Brazil	10	1.91%	2018.3

Table 1.2.12 Institutions with the greatest output of citing papers on "social responsibility for major projects"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Hong Kong Polytechnic University	44	21.36%	2018.1
2	Tongji University	30	14.56%	2018.2
3	Shenzhen University	18	8.74%	2018.7
4	Harbin Institute of Technology	16	7.77%	2018.6
5	University of Groningen	16	7.77%	2018.6
6	University of Adelaide	15	7.28%	2018.3
7	Shanghai Jiao Tong University	15	7.28%	2018.4
8	Tianjin University	14	6.80%	2017.9
9	Queensland University of Technology	13	6.31%	2018.5
10	The University of Hong Kong	13	6.31%	2018.5

2 Engineering development fronts

2.1 Trends in top 10 engineering development fronts

In the field of engineering management, this year's top 10 global engineering development fronts are "supply chain management system and method based on blockchain technology," "remote diagnosis and treatment system and method based on high-speed mobile network," "comprehensive emergency technology for urban safety," "epidemiological investigation technology and method based on big data," "research on simulation system and method based on digital twin," "agricultural tracking and monitoring system based on Internet of Things," "digital twin technology and method in smart city," "intelligent dispatching system for microgrid optimization," "infrastructure health monitoring system and method based on big data," and "management system and method of intelligent distribution service". The core patents are shown in Tables 2.1.1 and 2.1.2. These 10 engineering development fronts include agriculture, transportation, medicine, architecture, electronics, and many other disciplines. Among them, "supply chain management system and method based on blockchain technology," "remote diagnosis and treatment system and method based on high-speed mobile network," and "comprehensive emergency technology for urban safety" will be interpreted with emphasis, and the current development status and future trends will be interpreted in detail later.

(1) Supply chain management system and method based on blockchain technology

Blockchain technology is essentially a decentralized database, which is a new application mode combining distributed storage, point-to-point transmission, consensus mechanism, and cryptography. It can be divided into public chain, alliance chain, and private chain. Since its birth in 2008, the application of blockchain has extended to various fields of economy and society starting from digital cash, such as e-government, financial services, culture and entertainment, intelligent manufacturing, social welfare, education, and supply chain management. Supply chain is a system composed of logistics, information flow, and capital flow, in which suppliers, manufacturers, transportation enterprises, distributors, and retailers convert raw materials into final products and supply the products to consumers. Supply chain management is to design and manage seamless value-added processes between different organizations to meet the real needs of end customers. Blockchain, especially alliance chain, is naturally suitable for supply chain management and can realize large-scale cooperation among different organizations. However, in the practical application process, the supply chain is usually dynamic, and different supply chains also have interactive behaviors, while the alliance chain is relatively stable. Therefore, how to make alliance chain dynamically adaptable

Table 2.1.1 Top 10 engineering development fronts in engineering management

No.	Engineering development front	Published patents	Citations	Citations per patent	Mean year
1	Supply chain management system and method based on blockchain technology	15	43	2.87	2018.7
2	Remote diagnosis and treatment system and method based on high-speed mobile network	43	1 865	43.37	2016.8
3	Comprehensive emergency technology for urban safety	57	263	4.61	2018.4
4	Epidemiological investigation technology and method based on big data	31	892	28.77	2017.0
5	Research on simulation system and method based on digital twin	13	2	0.15	2018.9
6	Agricultural tracking and monitoring system based on Internet of Things	25	132	5.28	2016.7
7	Digital twin technology and method in smart city	28	7	0.25	2018.6
8	Intelligent dispatching system for microgrid optimization	21	46	2.19	2018.1
9	Infrastructure health monitoring system and method based on big data	14	33	2.36	2017.5
10	Management system and method of intelligent distribution service	15	81	5.40	2016.0

Table 2.1.2 Annual number of core patents published for the top 10 engineering development fronts in engineering management

No.	Engineering development front	2014	2015	2016	2017	2018	2019
1	Supply chain management system and method based on blockchain technology	0	0	0	0	4	11
2	Remote diagnosis and treatment system and method based on high-speed mobile network	3	9	7	10	4	10
3	Comprehensive emergency technology for urban safety	0	2	5	4	17	29
4	Epidemiological investigation technology and method based on big data	3	3	5	6	9	5
5	Research on simulation system and method based on digital twin	0	0	0	0	2	11
6	Agricultural tracking and monitoring system based on Internet of Things	2	5	6	3	4	5
7	Digital twin technology and method in smart city	0	0	0	3	6	19
8	Intelligent dispatching system for microgrid optimization	0	0	1	3	10	7
9	Infrastructure health monitoring system and method based on big data	1	1	1	1	7	3
10	Management system and method of intelligent distribution service	4	3	1	3	4	0

and how to realize the interaction between different chains are important problems to be solved, and cross-chain technology needs to be studied in depth. In addition, the blockchain itself can only ensure that the data will not be tampered after being uploaded, but cannot guarantee the authenticity of the uploaded data. The combination with the Internet of Things, big data, and artificial intelligence technology is expected to solve this problem. Furthermore, there is a common problem of blockchain that restricts the alliance chain's application in supply chain management, that is, "impossible trinity" of decentralization, security, and scalability, which needs to be weighed according to different scenarios. Therefore, it is an important research direction in the future to further develop cross-chain technology, combine emerging technologies such as Internet of Things, big data, and artificial intelligence, and optimize the fields of privacy protection, security, efficient authentication, cross-chain, and scalability.

(2) Remote diagnosis and treatment system and method based on high-speed mobile network

The remote diagnosis and treatment system based on high-speed mobile network is based on high-speed mobile network communication technology, and assists cross-regional medical care with low delay and high reliability through intelligent terminal medical equipment and integrated information collection terminal. At present, with the maturity of the remote communication technology of high-speed mobile network, a new solution is provided for the medical staff to implement more complex diagnosis and treatment behaviors, and the remote diagnosis and treatment technology has further shown broad application prospects in the fields of navigation and aviation security, disaster emergency rescue, and public health safety. In addition, with the application of artificial intelligence technologies such as Internet of Things and deep learning in related fields, the ability of remote diagnosis and treatment system to acquire and process information has been further improved, and the interactive service system and method around remote diagnosis and treatment have become a research hotspot in academic circles. However, in the engineering application management, the inconsistent data specifications and unfixed remote interactive environment caused by the difference of medical equipment terminals restrict the application of remote diagnosis and treatment system based on high-speed mobile network. Artificial intelligence technology based on edge computing and cloud–edge fusion provides support for high-speed processing and standardization of terminal information. Therefore, in the future, it is the main development trend of modern remote diagnosis and treatment system to develop a terminal service system of medical service that integrates and expands multi-source information flow, so that interactive information can be conveyed efficiently and accurately, and to improve the quality of remote medical service by combining edge computing technology with human–computer interaction technology.

(3) Comprehensive emergency technology for urban safety

The comprehensive emergency technology for urban safety is based on the information technology and realizes the functions such as information fusion, data collection, forecasting and early warning, situation assessment, and emergency decision-making through the establishment of urban safety emergency management system platform, so as to assist urban operation and emergency management. From the business perspective of urban safety, the comprehensive emergency response includes four aspects of prevention and emergency preparation, monitoring and early warning, emergency response and rescue, and post-event recovery and reconstruction. At present, the rapid development of emerging information technologies, such as Internet of Things, big data, cloud computing, and spatial geographic information technology, provides new technical support for the emergency management system, which makes comprehensive emergency technology show a broader application prospect. How to deeply integrate and apply the emerging information technology with business domains such as comprehensive emergency response and urban safe operation has become a new academic research hotspot. However, in practical engineering management applications, urban security involves multi-source and heterogeneous cross-level data information such as water, electricity, gas, heat, transportation, environment, and meteorology. Behind the appearance of excess information, there is the deficiency of theoretical models and the lack of effective information. Especially in emergency situations, the research and judgment of incomplete cross-domain information restrict the development of comprehensive emergency technology. Artificial intelligence technologies such as knowledge map, deep learning, and intelligent simulation can perceive data more accurately and efficiently and make decisions more intelligently. Therefore, in the future, how to combine safety engineering knowledge with artificial intelligence technology and mine multi-source heterogeneous big data to accurately identify and evaluate urban safety risks, and how to scientifically predict and comprehensively judge different disaster scenarios/decision-making stages and intelligently generate decision-making suggestions will be the two development trends of future research.

(4) Epidemiological investigation technology and method based on big data

Big data refers to the collection of complex data that exceeds the processing capacity of traditional data systems, goes beyond the scope of classical statistical analysis, and is difficult to perform single machine analysis with mainstream software tools and technologies. Through modern computer technology and innovative statistical methods, data can be purposefully acquired, managed, and analyzed, and valuable patterns and knowledge hidden in it can be revealed. Health care big data is a product of the integration of medicine and big data in the development process. Its main sources are health administration data, demographic and disease monitoring data, real-world health-related records (electronic medical records, medical images, physical examination data, etc.), scientific research data (biomarkers, clinical trials or cohort study multi-omics data), registration data (such as equipment registration, process registration, disease registration data), data from mobile medical devices, and data reported by patients. The establishment and development of big data collection and preprocessing, storage and management, computing mode and system, analysis and mining and visual analysis make health care big data widely used in public health such as disease diagnosis and treatment, residents' health management, etiology exploration, disease prediction and early warning model construction, disease prevention and control decision-making, etc. The development of health care big data will provide rich resources and a broad platform for scientific research such as epidemiological research of infectious diseases, etiology research of chronic diseases, co-morbid research of the elderly, and practical research, and provide an opportunity for epidemiology to refine research problems in richer and more complex data and open up new research directions. At the same time, to better transform the rich information in big data into knowledge and tools in time, it is necessary to construct new epidemiological research methods and develop big data analysis technology and statistical software for big data mining and analysis. The development of epidemiological investigation technology and method based on big data will help the construction of "digital public health".

(5) Research on simulation system and method based on digital twin

Digital twin is to establish a virtual model completely mapped with physical entities in a digital way, map the attributes, structure, state, performance, function, and behavior of physical entities to the virtual world, and simulate the behavior of physical entities in the real environment with the help of data, so as to observe, recognize, understand, control, and transform the physical world. Simulation is to simulate and reproduce the real dynamic system by using the model and evaluate and improve the system performance by performing various experiments on the simulation model. As an indispensable technology in product development and manufacturing, simulation has been widely used in various fields of industry. With the rapid development of digital twin and the increasing research on its theory and technology, simulation research and application based on digital twin, driven by data and model, has become a new hot research direction, including design simulation based on digital twin, production system simulation based on digital twin, and operation and maintenance simulation based on digital twin. However, massive multi-source heterogeneous data processing, accurate modeling and solution of complex models, real-time virtual–real interaction, and closed-loop control of digital twins bring new challenges to the simulation based on digital twins. Therefore, how to realize the construction, assembly, reconstruction, and consistency verification of multi-dimensional and multi-time scale dynamic models, how to analyze and fuse multi-source heterogeneous twin data in real time and efficiently, how to reduce the order and solve the simulation model in a unified way, how to reveal the coupling mechanism between twin data and model and realize the real-time simulation driven by model and data fusion are the main technical directions for realizing the simulation based on digital twin. In the future, through the creation of digital twins, the increasingly rich data will be combined with powerful model simulation, so as to help enterprises improve quality, increase efficiency, and save costs in product design, manufacturing, health management, remote diagnosis, intelligent maintenance, and shared services, which will be the main development trend of future research.

(6) Agricultural tracking and monitoring system based on Internet of Things

The agricultural tracking and monitoring system based on the Internet of Things is supported by the Internet of Things, which tracks and monitors all links in the agricultural product supply chain in real time, such as planting, picking, processing, and logistics of crops, and realizes real-time data collection, transmission, storage, and processing of data at all links, which is convenient for automatic, scientific, and efficient control of all links, and finally realizes refined and intelligent management of agriculture and quality control of agricultural products, thus promoting the development of smart agriculture. At present, the agricultural tracking and monitoring system based on the Internet of Things has shown a broad application prospect, which can be applied to crop pest identification and early warning, crop growth environment monitoring, agricultural product traceability and so on. With the application of cutting-edge technologies such as cloud computing, deep learning, and blockchain in agriculture, and the continuous advancement of Precision Agriculture and Agriculture 4.0, the research of agricultural tracking and monitoring system based on Internet of Things will usher in a rapid development stage. However, the agricultural tracking and monitoring system is faced with many complex problems, such as environmental factors like a wide variety of crops, temperature, light, soil nutrients, and air humidity affecting the growth of crops, frequent crop diseases and changeable symptoms, which make the data collected by the system have the characteristics of multi-source heterogeneity, high uncertainty, dynamic, and high matrix sparsity. Therefore, how to effectively process and analyze these data and apply them to intelligent agricultural management is a difficult point that needs to be overcome urgently. The combination of artificial intelligence technology such as deep learning, cloud computing technology, blockchain, 5G, intelligent unmanned aerial vehicle, and Internet of Things technology can complete the safe storage, analysis, and calculation of massive data, so as to monitor the operation of each link in the agricultural product supply chain more accurately, efficiently, and intelligently, thus creating a traceable, safe, and credible agricultural product supply chain. Therefore, in the future, how to combine artificial intelligence, cloud computing, blockchain, and Internet of Things and propose data analysis and processing methods with agricultural characteristics to improve the intelligence, automation, and scientific level of agricultural tracking and monitoring system based on Internet of Things, and how to provide expert-level agricultural management suggestions according to the continuous improvement of agricultural practice level and to improve the continuous penetration and application of cutting-edge technologies in practice will be the two major development trends of future research.

(7) Digital twin technology and method in smart city

With the urban governance and operation becoming more refined and precise in the digital age, the urban data resources urgently need to be transformed into urban digital assets in the era of connotative urbanization, and the concept of digital twins in the industrial field has been applied to the field of smart cities. Digital twins are virtual copies of material products or assets, which are updated in real time or periodically to make them as consistent as possible with their counterparts in the real world. Digital twin city means that all the components, elements, and activities of the city are copied into virtual cities, and the virtual cities interact with real cities in real time or at high frequency. In the future, cities themselves will gradually become the products of superposition of entities and virtual spaces of different scales and real-time dynamic communication among different groups. This is not only the integration of geographic information system, building information model and Internet of Things , but also the innovative integration of emerging technologies such as low-Earth-orbit satellite network, 5G, cloud computing, edge computing, real-time integration and call of multi-source heterogeneous data. According to domestic and foreign patents and articles, digital twin city technology has preliminary exploratory applications in urban emergency safety, community governance, smart education and medical care, smart tourism, and smart transportation. However, digital twin cities have changed the development path of traditional smart cities, focusing more on new digital spaces such as urban planning, construction, and operation and their communication modes. Driven by digital spaces, they promote the reconfiguration of land, capital, and talents in physical spaces, which in turn, constructs richer digital spaces and forms new urbanization of digital twins. The research difficulty lies in how digital twin cities provide a more interactive mode of human–computer interaction, more real-time super-large-scale computing, and a more self-learning iterative urban mechanism.

(8) Intelligent dispatching system for microgrid optimization

Microgrid refers to a small-scale power generation and consumption autonomous system that organically integrates distributed power sources, loads, energy storage devices, and monitoring and protection devices. The microgrid can achieve power balance, meet load demand, and ensure safe, stable, and economic operation of microgrid by optimizing dispatching and fully coordinating controllable units such as distributed generation, energy storage devices, and flexible loads. With the development of microgrid technology, its structure and function have undergone new changes, gradually expanding from single power structure to multi-energy forms including gas, heat, and electricity, and continuously merging with transportation systems such as electric vehicles and charging piles, information communication systems such as 5G base stations, etc., and evolving into integrated energy systems. At the same time, there will be a microgrid group composed of multiple microgrids in the same area, and the dynamic interaction process between microgrids and between microgrids and power systems is more complicated, so the optimal dispatch of microgrids is facing severe challenges. In recent years, artificial intelligence technology and 5G technology have made new energy power generation and load forecasting, system state perception, and optimal dispatching and decision-making more accurate and efficient. At the same time, the centralized collection and dispatching mechanism that the optimal dispatching system relies on gradually changes to the distributed point-to-point interactive negotiation mechanism, which greatly enhances the flexibility and scalability of the dispatching system. Therefore, it will be an important development trend in future research and development to fully consider the complementary characteristics of multi-energy coupling in microgrid (group), as well as the dynamic interaction and compatible operation with large power grid, and to build an optimized intelligent dispatching system by combining advanced artificial intelligence technology, 5G technology, and distributed dispatching architecture.

(9) Infrastructure health monitoring system and method based on big data

A large number of sensing devices are installed in the infrastructure health monitoring system to obtain environmental load and structural response information in real time. By analyzing massive monitoring data, possible structural damage can be identified and structural safety status can be recognized. The development of advanced intelligent sensing technology promotes the formation of infrastructure health monitoring big data, and makes infrastructure health monitoring system and method based on big data gradually become research hotspots, which will bring revolutionary changes to traditional health monitoring technology. Big data method is still in the exploratory stage in the field of infrastructure health monitoring, and its main technical directions include the research and development of intelligent monitoring equipment, analysis methods and efficient analysis, and calculation means of multi-source heterogeneous massive data. Tools like intelligent monitoring equipment and smart phones have broad application prospects in infrastructure health monitoring, which will provide more valuable information for infrastructure health monitoring; automatic and intelligent monitoring means produce a large amount of unstructured data, which requires in-depth study of effective data fusion methods, to comprehensively utilize the unstructured data and structured data, and maximize the value of massive multi-source heterogeneous data; health monitoring data contains a lot of noise and error information, and automatic data preprocessing is a problem to be solved in advance for health monitoring big data analysis; as an important task of infrastructure health monitoring, the key problem of damage identification based on big data is to extract characteristic indicators sensitive to structural damage but insensitive to changes in environment and operating load, and effectively judge the damage state of the structure after infrastructure cracking and extreme load; in the future, the monitoring of infrastructure health status will focus on groups, which will face the problem of insufficient analytical computing power or low computational efficiency, and it will become an inevitable trend to develop an efficient cloud computing platform. Therefore, the combination of big data analysis method with artificial intelligence, Internet of Things, and supercomputer technology is the development trend of infrastructure health monitoring in the future, which will provide a more reliable and effective guarantee for the safe operation of infrastructure.

(10) Management system and method of intelligent distribution service

Distribution service management system usually includes transportation management system and warehouse management system, which mainly systematizes and informationizes the traditional manual and document operation processes and presents them in the form of computer software system. At present, there are many software suppliers of distribution service management systems in the market, and this kind of system has been applied by enterprises in many fields, such as automobile manufacturing, food and medicine, retail fast-moving and electric commerce. In essence, the distribution service management system only enables the operation process of enterprises to be efficiently managed, and the data can be accurately shared, but it cannot provide excellent decision-making schemes for enterprises in operation, and most of the decisions in enterprises still rely on the human brain at present. Intelligent distribution service management system refers to the distribution service management system embedded with intelligent decision algorithm engine. Based on the current situation of business processes, input data and owned resources of enterprises, it can use operational optimization algorithm to generate the optimal decision scheme through complex calculations for direct use by enterprises or as decision support. Operational optimization algorithms mainly include branch-and-price algorithm, dynamic programming algorithm, heuristic algorithm based on column generation, tabu search algorithm, variable neighborhood search algorithm, and large neighborhood search algorithm. These algorithms are the mainstream methods to solve practical problems of enterprises, which are very efficient and have been widely used. In recent years, many scholars have tried to apply artificial intelligence algorithms based on neural networks, such as reinforcement learning and deep learning to solve the optimization problem in the field of distribution services, which has become a hot spot in current academic research. However, the related methods and theoretical achievements are still not rich, and the effect of related algorithms is still not as good as that of traditional operational optimization algorithms. It is the future research trend to combine artificial intelligence algorithm based on neural network with traditional operational optimization algorithm and use their respective advantages to solve the optimization problem in the field of distribution service.

2.2 Interpretations for three key engineering development fronts

2.2.1 Supply chain management system and method based on blockchain technology

Supply chain is composed of many participants, and there is a lot of interaction and cooperation. Information is discretely stored in each link and system, which lacks transparency. The unsmooth information transmission makes it difficult for each participant to accurately understand the real-time status and existing problems of related matters, which affects the collaborative efficiency of supply chain. When there is a dispute between the subjects, it takes time and effort to give evidence and pursue responsibility. In the future, the market scope of enterprises is becoming larger and larger, and the logistics links are characterized by multi-regions and long time span, which requires intelligent and efficient anti-counterfeiting traceability. In addition, many small-and medium-sized enterprises in the supply chain are difficult and expensive to finance, which often affects their effective operation and then affects the performance of the whole supply chain. Supply chain finance is one of the methods to solve this problem, which has been consistently sought after by the industry when it was put forward, but it has been limited by the problem of risk control cost for a long time and cannot play its ideal role.

Blockchain has the advantages of non-tamperable data, traceability, cost reduction, trust building, etc., which can solve the above pain problems in traditional supply chain management to a great extent. Non-tamperable data: Blockchain uses asymmetric encryption and hash algorithm to ensure that data recording and transmission are true, non-tamperable, and non-repudiation. Traceability: the main body interaction of supply chain information is realized through embedded identification technology and pervasive algorithm, and a unique and continuous "chain" is constructed in public "blocks" according to time series, thus ensuring the uniqueness and traceability of supply chain transaction information. Cost reduction: Blockchain technology supported by timestamp, password protection, node protection, and other technologies can ensure the security and accessibility of supply chain data, which makes blockchain naturally meet the cost control needs of supply chain. Trust building: Blockchain is known as "trust machine." In the blockchain system, the consensus mechanism solves and guarantees the consistency and correctness of each uploaded information data on all chain nodes, ensures that the data blocks can be directly written and recorded in the blockchain without relying on the approval of the centralized organization, and then enters the whole traceability system to complete the operation.

Meanwhile, it should be pointed out that there are some shortcomings in the application of blockchain in supply chain. For example, the privacy protection technology system for the concealment of trading behavior and smart contracts is still incomplete; there may be security loopholes and backdoor influence in the implementation of intelligent contract code, which may lead to business fraud and other risks; information interaction and value transfer between different blockchains need to be solved urgently; with the increase of the number of nodes, the communication cost will increase sharply, which will affect its scalability and system availability in terms of the number of users and transactions.

From the perspective of patent analysis, supply chain management systems and methods based on blockchain mainly include two categories, that is, supply chain traceability methods and systems based on blockchain and supply chain financial management methods and systems based on blockchain.

(1) Supply chain traceability method and system based on blockchain

It comprises the following steps: composing a predetermined number of monomer products into a product logistics unit, equipping the product logistics unit with a satellite positioning chip, acquiring position information, and generating a current hash value. The private key of batch products is stored in the blockchain and the blockchain is associated with the current product batch. By recording logistics traceability information, we can ensure the integrity of logistics information records, prevent the loss of logistics traceability information, and facilitate the query of logistics traceability information.

(2) Supply chain financial management method and system based on blockchain

It mainly includes supply chain financial platform and risk assessment platform. The supply chain financial platform includes supply service platform of upstream raw material, brand service platform, processor service platform, and downstream store service platform. The risk assessment service platform includes an industry big data assessment module and a financial transaction service platform, wherein the industry big data assessment platform is connected with a risk early warning module and the financial transaction service platform is connected with a transaction asset service module. The supply chain financial service platform based on blockchain is helpful to understand financial services in detail, so as to make financial investment and reduce investment risks.

It can be seen that the blockchain mainly solves the trust and security problems of transactions. Based on this problem, this paper puts forward some innovations such as distributed ledger, asymmetric encryption and authorization technology, consensus mechanism, and intelligent contract. Blockchain's decentralization, openness, autonomy, non-tamperable information, and anonymity provide good support for supply chain management.

In terms of the number of published patents, the top two countries are China and the United States (Table 2.2.1). The citations per patent is 14.27 and 22, respectively (Table 2.2.1). At present, China focused on two fields, blockchain-based supply chain tracking and traceability methods and blockchain-based supply chain financial anti-counterfeiting tracking methods, the first method mainly use radio frequency identification, near field communication, and QR codes to generate product tags and complete the transaction process; the second method realizes the agreement between the buyer and the seller through smart contracts, logistics supervision and financial evaluation, to reduce cumbersome procedures and improve processing speed. The United States focused on blockchain-based supply chain traceability methods to manage the transportation of goods from the origin to the destination, and uses smart contracts to speed up transactions and ensure compliance with operating procedures.

The top one institution in the number of patents is University of Electronic Science and Technology of China (Table 2.2.2), which focused on supply chain financial management methods based on sovereign blockchain technology and blockchain-based freight logistics management methods. The supply chain financial management method based on sovereign block chain technology mainly uses sovereign block chain technology to build a block chain application platform suitable for China's supply chain finance, that can improve the security and traceability of supply chain financial applications, reduce transaction costs, and realize the supervision of the entire process of supply chain finance; the blockchain-based freight logistics management method combines sub-blockchains to establish a blockchain platform to realize the trustworthy data sharing of the entire freight logistics process, and the problem of difficulty obtaining data of freight logistics in the later stage is to be solved.

2.2.2 Remote diagnosis and treatment system and method based on high-speed mobile network

The remote diagnosis and treatment system is derived from English "telemedicine", which is the product of the rapid development of telecommunication technology in the 20th century. Early remote diagnosis and treatment was completed by telephone and short-range radio, which mainly served the exchange of medical information and assisted the areas with asymmetric medical resources to complete diagnosis and treatment activities. With the innovation of modern communication technology, its connotation is constantly enriched. Modern telemedicine service system includes resource providers, service demanders, and interactive communication devices, which has gradually evolved

Table 2.2.1 Countries with the greatest output of core patents on "supply chain management system and method based on blockchain technology"

No.	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	11	84.62%	157	78.11%	14.27
2	USA	2	15.38%	44	21.89%	22.00

Table 2.2.2 Institutions with the greatest output of core patents on "supply chain management system and method based on blockchain technology"

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	University of Electronic Science and Technology of China	3	23.08%	35	17.41%	11.67
2	Wuxi Jingtum Network Technology Co., Ltd.	2	15.38%	21	10.45%	10.50
3	Qianhai Yunlian Technology Shenzhen Co.	2	15.38%	15	7.46%	7.50
4	Hangzhou Yunxiang Network Technology Co.	2	15.38%	60	29.85%	30.00
5	Zhonglian Technology Co., Ltd.	1	7.69%	8	3.98%	8.00
6	Guangdong University of Technology	1	7.69%	18	8.96%	18.00
7	Skuchain Inc.	1	7.69%	37	18.41%	37.00

from the early single information exchange service to the information system technology facing multi-party real-time interaction in complex scenes such as emergency rescue, health care, and emergency treatment. The construction of modern remote diagnosis and treatment system is the result of multidisciplinary integration, including modern communication, Internet of Things, intelligent medical equipment, edge computing, and distributed artificial intelligence, which makes remote diagnosis and treatment system no longer limited to the exchange of information, but can dig deeper into the value of information itself and interaction process. While ensuring the timeliness of data transmission, it can further improve the presentation of effective information in the interactive process, and assist medical staff to improve the service level of remote diagnosis and treatment according to the interactive information.

In engineering application management, the inconsistent data specifications and unfixed remote interactive environment caused by the differences of medical equipment terminals restrict the application of remote medical service system based on high-speed mobile network. Therefore, the development and integration of expansive medical service terminal equipment and remote medical service based on the combination of edge computing technology and human–computer interaction technology are the main trends to improve the efficiency of remote medical service in the future. From the patent analysis, the remote diagnosis and treatment system and method based on high-speed mobile network mainly include medical Internet of Things, computer aided diagnose, medical robots, diagnosis and treatment information retrieval, and telemedicine edge computing technology.

(1) Medical Internet of Things

Medical Internet of Things is a product of the integration and development of modern intelligent Internet of Things and high-speed communication technology. It is an information management system that connects terminal facilities such as medical patients and pharmaceutical equipment and supports real-time interaction of diagnosis and treatment information. In the field of engineering management, medical Internet of Things can complete the functions of automatic information identification, key information location, automatic data collection, traceability tracking, comprehensive information management, regional information sharing and so on under the medical interconnection environment. However, at present, due to the inconsistent information collection standards of IoT devices, the degree of human–machine interconnection is not high. The medical Internet of Things technology based on artificial intelligence can effectively standardize the data information in the terminal equipment, so that the medical Internet of Things technology can effectively serve modern medical management.

(2) Computer aided diagnosis

Computer aided diagnosis (CAD) is a system that helps doctors interpret diagnosis and treatment data. CAD mainly deals with a large amount of information generated by imaging technology in X-ray, MRI, and ultrasonic diagnosis in the early stage, thus reducing the time of reading films for medical staff in imaging departments. At present, in the field of engineering practice, CAD has been widely used in specialized departments. Although it can assist medical care to complete diagnosis and treatment in some links, it is limited by the multi-source and multi-modal types of diagnosis and treatment data, and CAD technology needs manual intervention to complete diagnosis and treatment. With the development of artificial intelligence technology based on human–machine collaboration, it is expected to realize intelligent auxiliary diagnosis and treatment system based on human–machine coupling in the future.

(3) Medical robots

Medical robot is a kind of robot that assists or replaces medical staff to complete diagnosis and treatment services by constructing precise electrical devices. It contains many kinds. For example, the surgical manipulator used in surgery in ocean navigation or remote areas can complete more accurate and less invasive surgery; the monitoring robot in COVID-19 epidemic can complete the collection of personal sign information without cross infection; and the remote control robot used in remote surgery can assist doctors to complete complex surgical operations across regions. At present, in the field of engineering practice, medical robots are closely integrated with use scenarios, but their environmental adaptability is weak. Developing medical robots suitable for human–machine coupling environment is the mainstream development direction in the future.

(4) Diagnosis and treatment information retrieval

Diagnosis and treatment information retrieval refers to the process of inquiring and displaying information in the diagnosis and treatment system. Traditional diagnosis and treatment information retrieval is completed by the information system built in medical institutions, which requires low data retrieval efficiency. In the process of remote diagnosis and treatment, in order to complete high-quality remote diagnosis and treatment activities, the diagnosis and treatment information retrieval technology should be used to quickly locate multi-modal related information including electronic medical records, pathological images, and diagnosis and treatment videos. In engineering management, classical information retrieval techniques include vector space model and probability model based on structured data. However, due to the modal diversity of remote diagnosis and treatment system data, the existing retrieval methods are generally inefficient. With the development of semantic understanding technology based on deep learning, realizing high-level semantic understanding and association retrieval of multimodal medical data is a main direction of medical information retrieval in the future.

(5) Telemedicine edge computing

Telemedicine edge computing refers to providing the nearest intelligent diagnosis and treatment service by integrating the computing resources stored, transmitted, and managed on the side of resource request or data sources in the process of completing the intelligent remote diagnosis and treatment service. For example, the mobile reading terminals in mobile medical treatment can assist doctors to automatically analyze and display diagnosis and treatment information; distributed shared storage used in remote consultation can support real-time access and storage of multi-party data in remote diagnosis and treatment. With the application of high-speed communication technologies such as 5G, modern edge computing can complete more complex multi-modal diagnosis and treatment data analysis and medical resource request allocation, and can partially delegate the original computing resources deployed in the cloud-to-edge medical terminals, thus completing data analysis and preprocessing at edge terminals, reducing the communication load pressure during remote diagnosis and treatment, and reducing the risk of medical information leakage. At the same time, with the development of distributed artificial intelligence technology, edge computing will play an important role in the future remote diagnosis and treatment system.

In terms of the number of patents published, the top two countries in the number of patents are the United States and South Korea (Table 2.2.3), which mainly include remote consultation systems with interactive ability and long-term real-time nursing monitoring systems with active early warning capability. The sensing information is rich, and some of them use CAD technology based on edge computing, but China is still in the catch-up stage. The top three countries in citations per patent are the United Kingdom, the United State, and the Netherlands (Table 2.2.3). Their core contents are related to abnormal information early warning of patients with chronic diseases such as diabetes, as well as remote health monitoring in special environments such as ocean voyage. From the patent output cooperative network diagram (Figure 2.2.1), a cooperative relationship has been formed between the United States and the Netherlands in the key areas of remote video transmission in the mobile network. The top two institutions in the number of patents are: MI Express Care Licensing Company and Koninklijke Philips Electronics NV (Table 2.2.4), but they are limited to the field of long-term health monitoring and are mainly based on multiple types of sensors. From the cooperation network diagram of patent output institutions (Figure 2.2.2), the scale of regional cooperation has been initially formed, but there is no cross-regional cooperation network, in which Koninklijke Philips Electronics NV and Ishihara Corporation (U.S.A.), OBS Medical Ltd. and E-SAN Limited in the United Kingdom have cooperation in the field of chronic disease monitoring, and the core technology involves primary semantic diagnosis and treatment information retrieval. Enterprises in our country are in the synchronous catch-up stage in the field of chronic disease monitoring and remote diagnosis and treatment, but thanks to the development of high-speed mobile communication networks in China, the remote diagnosis and treatment technology in special fields such as telemedicine consultation and telemedicine robots in China has certain first-mover advantages.

2.2.3 Comprehensive emergency technology for urban safety

Urban buildings are dense, the infrastructure network is complex, and the subsystems are closely coupled in structure and function, which will show high vulnerability under the hazards of emergencies. In 1989, the concept of “safe city” was formally put forward in the first academic conference on

Table 2.2.3 Countries with the greatest output of core patents on “remote diagnosis and treatment system and method based on high-speed mobile network”

No.	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	USA	31	51.67%	1581	75.14%	51.00
2	South Korea	10	16.67%	34	1.62%	3.40
3	China	8	13.33%	26	1.24%	3.25
4	Germany	2	3.33%	26	1.24%	13.00
5	Japan	2	3.33%	3	0.14%	1.50
6	UK	1	1.67%	364	17.30%	364.00
7	Netherlands	1	1.67%	34	1.62%	34.00
8	Canada	1	1.67%	28	1.33%	28.00
9	Finland	1	1.67%	25	1.19%	25.00
10	Denmark	1	1.67%	17	0.81%	17.00

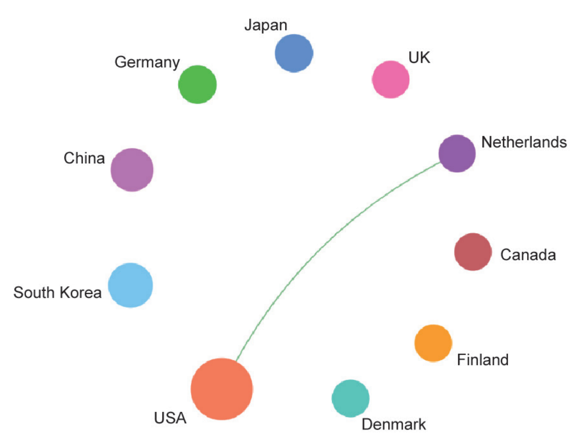

Figure 2.2.1 Collaboration network among major countries in the engineering development front of “remote diagnosis and treatment system and method based on high-speed mobile network”

Table 2.2.4 Institutions with the greatest output of core patents on “remote diagnosis and treatment system and method based on high-speed mobile network”

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	MI Express Care Licensing Company	7	11.67%	26	1.24%	3.71
2	Koninklijke Philips Electronics NV	2	3.33%	1385	65.83%	692.50
3	Ishihara Corporation (U.S.A.)	1	1.67%	1351	64.21%	1351.00
4	E-SAN Limited	1	1.67%	364	17.30%	364.00
5	OBS Medical Ltd.	1	1.67%	364	17.30%	364.00
6	Abbott Diabetes Care Inc.	1	1.67%	52	2.47%	52.00
7	KT Freetel Co., Ltd.	1	1.67%	30	1.43%	30.00
8	Telehealth Broadband, LLC	1	1.67%	28	1.33%	28.00
9	Verathon Inc.	1	1.67%	28	1.33%	28.00
10	INCREA OY	1	1.67%	25	1.19%	25.00

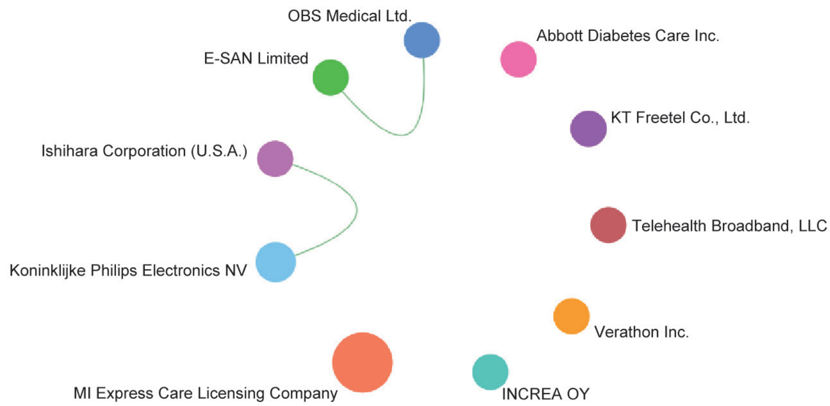

Figure 2.2.2 Collaboration network among major institutions in the engineering development front of "remote diagnosis and treatment system and method based on high-speed mobile network"

"Preventing Accidents and Losses." After the "9·11" incident in the United States in 2001, the concept of Emergency Management was put forward. In recent years, with the rapid development of urbanization, the risk factors of urban security have increased dramatically and the comprehensive emergency technology for urban safety has attracted more and more attention. Urban safety comprehensive emergency technology is an interdisciplinary subject, which covers many research fields, such as information system, safety engineering, system engineering, and decision management. The rapid development of emerging information technologies, such as Internet of Things, big data, and cloud computing, has provided new impetus for comprehensive emergency technology. Scientific issues such as emergency big data modeling, information sharing and full-process application, and emergency decision-making theories and methods supported by emerging information technologies have become emerging academic research hotspots and are considered to be one of the important directions for the future development of emergency management.

In practical engineering management applications, urban safety data types are cross-domain, cross-level, and cross-modal, and data information is often incomplete in emergency situations. How to integrate domain knowledge and models, multi-source heterogeneous and incomplete data, and emergency management business needs is an urgent problem to be solved in urban safety comprehensive emergency technology. From the patent analysis, the comprehensive emergency technologies for urban security mainly include big data fusion, urban risk monitoring and early warning, urban risk assessment, emergency intelligent decision support, and visualization of emergency map.

(1) Big data fusion

Big data fusion is to establish multi-dimensional and multi-granularity relationships among data, information, and knowledge fragments by means of models, entity links, and relationship deduction, so as to realize knowledge interaction at more levels. There are many kinds of data and information related to urban safety. From the perspective of emergency technology application, big data fusion can partially solve the problems of one-sided understanding and wrong decision-making caused by information fragmentation, but it still needs to conduct more efficient and accurate fusion management for emergency big data to support comprehensive emergency decision-making of urban safety.

(2) Urban risk monitoring and early warning

Risk monitoring and early warning uses the Internet of Things technology, and connects any article with the Internet through information sensing equipment such as radio frequency identification, infrared sensor, global positioning system, and laser scanner according to the agreed protocol, and exchanges and communicates information to realize intelligent identification, positioning, tracking, monitoring, and management of articles. The Internet of Things provides a great deal of data information for urban risk monitoring and early warning, which is different from the traditional technology. How to apply the Internet of Things technology to improve the monitoring ability of urban emergency, and how to study the analysis model based on new data to improve the accuracy of early warning are the problems that need to be focused on and solved in the future.

(3) Urban risk assessment

Risk assessment needs all kinds of disaster analysis models to predict and simulate various elements of urban operation. Disaster analysis models are gradually developing to refinement. Large-scale input of data and large-scale calculation ensure the accuracy of calculation, but also increase the calculation time. High-precision disaster simulation based on cloud computing can provide capacity support for practical risk assessment.

(4) Emergency intelligent decision support

With the development of science and technology, artificial intelligence technology is gradually applied to emergency intelligent decision. Robot, language recognition, image recognition, natural language processing, and expert system are becoming mcreasingly mature. However, the actual emergency scenarios are complex and changeable, and it is often required to make decisions quickly based on known massive information. The comprehensive application of artificial intelligence for emergency decision scenarios needs further exploration.

(5) Visualization of emergency map

One map refers to collecting, managing, analyzing, and displaying the data related to geographical distribution in space by using a geographic information system. Combining geography and cartography, remote sensing, and computer science, visualization of the emergency map has been widely used in the field of urban safety and emergency response. Multi-source data are displayed based on the same base map, which brings a lot of convenience for emergency decision-making. Meanwhile, how to realize efficient integration and fast and effective visual display of massive data in complex urban situations brings new challenges to urban safety emergency decision-making based on one map.

The top two countries in terms of the number of published patents are China and the United States (Table 2.2.5). The top two countries in terms of citations per patent are China and the United States (Table 2.2.5). The number of patents in different institutions is equal (Table 2.2.6).

The core patents in the field of urban safety comprehensive emergency technology in different countries have different research characteristics. China pays attention to the application of the Internet of Things technology, and puts forward a comprehensive evaluation system related to urban multi-dimensional security, such as the road traffic information cloud computing and cloud service realization system based on the Internet of Things, the urban natural gas intelligent leakage alarm system, and the dynamic monitoring and early warning system of the urban underground pipeline corridor based on the Internet of Things. These systems skillfully apply the advanced technologies such as the Internet of Things and big data to the urban comprehensive evaluation, monitoring, and early warning. The United States pays more attention to anti-terrorism security issues, such as non-military unmanned aerial vehicle signal detection and video feedback, accurate positioning of construction personnel, and emergency response research, while Japan pays attention to natural disasters such as earthquake and tsunami. Its research content is basically related to escape guidance and disaster monitoring, such as the escape guidance system used in earthquake, fire or tsunami, and the urban earthquake intelligent monitoring and early warning system. The research foci of different institutions are also different. For example, Zhejiang University of Technology focuses on the research of accurate positioning of urban vehicles and proposes an information center system with a data receiving and storage server of a global position system, which can monitor road traffic information on a large scale in real time. GSM Solution Inc. attaches importance to image processing and processing, and puts forward a system based on geographic information systems and Internet subsystems to process landscape images, geographic information system data, and measurement information in real time and determine the target locations. READ ENG KK pays more attention to the research of guiding personnel to escape correctly in disaster events and puts forward an indication system to determine the best evacuation area according to the disaster location information and current location information, to help people escape efficiently in disasters such as earthquakes.

Table 2.2.5 Countries with the greatest output of core patents on "comprehensive emergency technology for urban safety"

No.	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	28	57.14%	175	66.29%	6.25
2	USA	12	24.49%	63	23.86%	5.25
3	South Korea	6	12.24%	17	6.44%	2.83
4	Japan	3	6.12%	9	3.41%	3.00

Table 2.2.6 Institutions with the greatest output of core patents on "comprehensive emergency technology for urban safety"

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	Jiangsu Posts & Telecommunication Planning & Designing Institute Co., Ltd.	1	2.04%	50	18.94%	50
2	Redsky Technologies Inc.	1	2.04%	34	12.88%	34
3	Zhejiang University of Technology	1	2.04%	25	9.47%	25
4	Guangzhou Hanrun Information Technology Co., Ltd.	1	2.04%	25	9.47%	25
5	Hangzhou Chenqing Heye Technology Co., Ltd.	1	2.04%	12	4.55%	12
6	Korea Gas Safety Corporation	1	2.04%	8	3.03%	8
7	Shenzhen Yichuang Information Technology	1	2.04%	8	3.03%	8
8	GSM Solution Inc.	1	2.04%	6	2.27%	6
9	READ ENG KK	1	2.04%	6	2.27%	6
10	Beijing Beipai Design and Research Institute Co., Ltd.	1	2.04%	5	1.89%	5

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