IX. Engineering Management

1 Development trends of engineering research hotspots

In engineering management, engineering research hotspots, globally, are mainly focused in the following 10 fields: fuzzy group decision method, business model dynamics and innovation, service platform and enterprise information system based on the Internet of Things, human resources: influences of organizational performance and competitiveness, container allocation and liner transport network, simulation-based medical teaching, optimum status-based maintenance strategy, multi-objective particle swarm optimization, bicycle sharing system, and tradable electronic right-of-way mechanism. The respective situations of the core papers in each of these fields are shown in Table 1.1 and Table 1.2. The abovementioned 10 engineering research hotspots centrally cover mathematics, economy, industry, computer science, information and automation, and other disciplines. Of these research hotspots, four are included in the emerging frontier category: service platform and enterprise information system based on the Internet of Things, optimum status-based maintenance strategy, multi-objective particle swarm optimization, and bicycle sharing system; six of the research hotspots are included in the traditional profound research category: fuzzy group decision method, business model dynamics and innovation, human resources: influences of organizational performance and competitiveness, container allocation and liner transport network, simulation-based medical teaching, and tradable electronic right-of-way mechanism; there is no hotspot that is subject to the subversive frontier category.

1.1 Fuzzy group decision method

Along with the development of science, technology, and production, issues geared to an individual decision maker have been on the decrease; there have been more and more group decision issues geared to multiple decision makers. Furthermore, owing to the limitations and fuzziness of human understanding, during evaluation of these issues, we shall apply the concept of fuzziness, which is more objective and more suitable to handle certain complicated decision issues. Fuzzy group decision refers to behaviors of several individuals in making a unified decision on a certain issue by using fuzzy mathematics tools while considering multiple influencing factors; it requires the aggregation of group member preferences under a fuzzy environment and the formation of a group preference, followed by sorting out decision schemes according to the

Table 1.1 Top 10 engineering research hotspots in engineering management

No.	Engineering research hotspots	Core papers	Citation frequency	Average citation frequency	Mean year	Proportion of consistently cited papers	Patent-cited publications
1	Fuzzy group decision method	40	2146	53.65	2011.80	35.0%	2
2	Business model dynamics and innovation	48	2584	53.83	2011.92	10.4%	0
3	Service platform and enterprise information system based on the Internet of Things	50	2227	44.54	2013.02	36.0%	0
4	Human resources: influences of organizational performance and competitiveness	36	1764	49.00	2012.47	22.2%	1
5	Container allocation and liner transport network	33	1227	37.18	2012.64	24.2%	0
6	Simulation-based medical teaching	34	1166	34.29	2012.88	20.6%	1
7	Optimum status-based maintenance strategy	38	1260	33.16	2013.66	13.2%	0
8	Multi-objective particle swarm optimization	39	1114	28.56	2013.92	41.0%	0
9	Bicycle sharing system	43	1165	27.09	2013.51	20.9%	0
10	Tradable electronic right-of-way mechanism	36	844	23.44	2013.03	5.6%	1

Table 1.2 Annual number of core papers belonging to each of the top 10 engineering research hotspots in engineering management

No.	Engineering research hotspots	2011	2012	2013	2014	2015	2016
1	Fuzzy group decision method	19	14	4	2	1	0
2	Business model dynamics and innovation	21	16	7	2	2	0
3	Service platform and enterprise information system based on the Internet of Things	7	11	6	26	0	0
4	Human resources: influences of organizational performance and competitiveness	10	7	11	8	0	0
5	Container allocation and liner transport network	7	9	9	5	3	0
6	Simulation-based medical teaching	6	8	8	8	4	0
7	Optimum status-based maintenance strategy	7	1	7	8	13	2
8	Multi-objective particle swarm optimization	0	3	12	10	13	1
9	Bicycle sharing system	5	3	12	13	8	2
10	Tradable electronic right-of-way mechanism	6	7	11	5	6	1

group preference or selecting the most favorable scheme for the group. Presently, the key issues of fuzzy group decision research hotspots include fuzzy information aggregation method, fuzzy decision information measure theory, fuzzy preference relation, and the respective sorting methods. Based on fuzzy information, it is of great significance for exerting the role of experts in making group decisions to the largest extent and eliminating irrational factors to research how to aggregate preferences of various subjects and form a group preference, as well as sorting alternative schemes according to the respective attributes in the group decision process.

1.2 Business model dynamics and innovation

The concept of a business model was first proposed by Bellman et al. A business model is subject to an operation theory for organizations or enterprises; it is an expression of strategic thinking. A business model refers to the basic logic of an enterprise creating value, namely the method an enterprise applies to provide customers with products and services and earn profits in a certain value chain or value network. It is a system that consists of various constituents, the corresponding connections, and "dynamic mechanism" of the system. Business model innovation refers to the creative changes of basic logic generated by value creation of the enterprise, namely the introduction of a new business model to the social production system to create value for the customer and the enterprise itself. Along with variations of business environment and information technologies, business model conversion and innovation have become new research hotspots.

This research subject mainly concentrates on four aspects: the dynamic evolution, innovation, and conversion of the business model of the enterprise; business model innovation of SMEs; business model innovation and technical innovation; the essence, classification, and key abilities of the business model, and other theoretical research. Among these, innovation and conversion of the enterprise business model under new environments have drawn the attention of many scholars, and exerted great influence on theoretical research on the essence of the business model.

Research on business model innovation mainly covers management, psychology, finance, sociology, and other disciplines; it has interdisciplinary features and has already accumulated a large sum of studies. It is a profound hotspot of traditional research.

1.3 Service platform and enterprise information system based on the Internet of Things

In modern business, frequent variation of customization demand and specialization of operation flow requires the enterprise to collect real-time data and have an effective and highly efficient operation flow. A service platform is capable of managing the product life cycle and offering information support for data integration and intelligent interaction. While an enterprise information system is capable of combining technologies of operation flow management, work flow management, enterprise application integration, service-oriented architecture, and network computing. Meanwhile, the Internet of Things is capable of processing real-time and heterogeneous data, and realizes the real-time sharing and intelligent collection, transmission, processing, and execution of status information among objects. Applications of the Internet of Things include applications of a great variety of equipment and heterogeneous networks of diversified specifications; it aims at establishing a formalized and systematic service platform and an enterprise information system that supports data collection, communication, and all decision activities. Current research areas within the hotspot of service platform and enterprise information system based on the Internet of Things mainly include five aspects: cloud manufacturing service system based on the Internet of Things, enterprise cloud service architecture, enterprise information system architecture analysis, framework of emergency response decision support system, and configurable information service platform based on the Internet of Things.

1.4 Human resources: influences of organizational performance and competitiveness

With the arrival of the knowledge economy age, the competition for talent has been increasingly fierce. Human resources are the most important resources for an organization to obtain competitive advantages. Human resource management is an organizational factor that is conducive for improving the total performance level of an enterprise; it has been deemed as a "potential contributor that establishes and realizes the mission, vision, strategy, and target of an organization." Enterprise human resource research mainly carries out fundamental analysis in three areas: human capital, organizational routines, and turnover intention. First, in terms of human capital, the research is mainly based on resource base theory and deems human capital as a core resource of an enterprise; in addition, it indicates that the corresponding competitive advantages could help the enterprise to improve its organizational performance during long-term development; meanwhile, by integrating itself with specific research scenarios, the appearance and functions of human capital are analyzed on the macroscopic and microscopic levels. Second, in terms of organizational routines, on one hand, by being based on the perspective of organizational learning and focusing on analyzing the formation and variation process of organizational routines from the individual and organizational levels, the research has demonstrated through analysis on the time sequence that updates of organizational routines could improve organizational performance and increase the innovative power of the enterprise; on the other hand, the research points out that organizational routines could be deemed as one of the countermeasures of the enterprise when dealing with external environment changes; by actively searching for changes in organizational routines, it could help the enterprise to develop in a more sustainable and steady manner. Finally, in terms of turnover intention, on one hand, the research has analyzed the influences of turnover on enterprise performance by using the long-term data, and discussed different turnover types (voluntary resignation and dismissal), enterprise scales, and industrial background in detail; on the other hand, the research has paid attention to the new phenomenon of group resignation, deeply discussed causes and consequences of group resignation, and analyzed the phenomenon from two aspects: theory construction and empirical analysis. In recent years, an opinion that has been universally agreed by scholars has been that human resource management serves as a strategic contributor to organizational performance, that is, strategic human resource management will gradually replace the traditional human resource management; this is becoming a guiding ideology for organizations, especially knowledge-based organizations, in conducting human resource management practices.

Research on human resources: influences of organizational performance and competitiveness mainly covers economics, management, the science of personnel, and other disciplines; it has interdisciplinary features and has already accumulated a large sum of studies. It is a profound hotspot of traditional research.

1.5 Container allocation and liner transport network

Container transport is a highly efficient transport mode with high benefits in the modern circulation field; it is convenient for conducting handling operations and completing transport tasks by using large handling machinery and large carrier vehicles. As container transport has more advantages than other ocean shipping modes, container technology has become an integral part of the ocean shipping field.

Container liner transport is an operation mode in which the container liner company provides standardized and iterative container cargo transport services for non-fixed shippers based on specified operation rules between fixed affiliated ports on fixed routes according to the pre-determined schedule, and calculates freight based on "container freight rates." Therefore, a container liner transport network consists of the container port, container route network, and vessels running on the route network. Presently, research hotspots mainly include liner transport route network design and optimization, container transport in the liner network, fleet deployment in the liner transport network, and container vessel scheduling optimization. Among these, the key technology applied in the liner transport network design is the approximation solution of the mixed integer planning model. Most of the current research has focused on expanding various constraint details of the route network, such that the parameter conditions of the mixed integer model could more comprehensively and better approach the actual transport conditions. Various complex mathematics tools are used to search for creative solutions, so that the model solution could better reflect the real case. Furthermore, complex network theory is used as the basic theory of global linkage transport networks, but research on the theory in this hotspot is still in the explorative basic research stage. In the future, it will be necessary to continue carrying out further exploration and research.

Research on container allocation and liner transport network mainly covers transportation, economics, automation, computer science, railway transportation, and other disciplines; it has interdisciplinary features and is a profound hotspot of traditional research.

1.6 Simulation-based medical teaching

Along with the continuous development of the medical care field, computer science hardware technologies, and information technologies, the traditional medical care teaching and training mode is not able to satisfy patient requirements for medical care services any longer. Simulation-based medical teaching is an advanced training method; it develops a simulation system by applying virtual simulation technologies centered on computing technology, and uses it for assisting medical clinical teaching, doctor training, practical skill testing, technology learning, surgery planning and the like, so as to improve the accuracy of doctors in clinical diagnoses, safety, controllability, and timeliness of surgeries, and ensure the quality of medical care. Research on simulation-based medical teaching covers simulation technologies, design of methods and conceptual frameworks, research on task reports, design and application of teaching practices, practice effect analysis, and mechanism research, as well as clinical conversion of training achievements and many other issues; it comprehensively utilizes medical simulation, training theory, empirical research, as well as theories and methods of translational science. The current research hotspots are computer graphics, artificial intelligence, deep learning, man–machine interface technology, biofeedback, sensor technology, and parallel real-time computer science technology; furthermore, it also includes research on human behaviors and applications of other key technologies in the medical care profession. In the future, the research and development of intelligent and self-adaptive simulated patients with high simulation degree will be key factors in the medical care industry for patient services.

1.7 Optimum status-based maintenance strategy

Modern production equipment features high-technology contents, complex structures, and strong system characteristics. Their faults feature a very high level of randomness; in addition, these may cause severe losses, or even disasters. Thus, a reasonable maintenance strategy is of great importance. Developing from pure fault maintenance before the 1950s to preventive maintenance on a regular basis, the concept of equipment maintenance is now transforming towards optimum status-based maintenance.

An optimum status-based maintenance strategy is an advanced maintenance method. It obtains relevant information that reflects the equipment state through status monitoring technology, judges the equipment state, and identifies early signs of defect states through signal analysis, fault diagnosis, reliability assessment, service life prediction and the like, with the aim of analyzing and predicting defect conditions and the development trends of defect states, and recommending the best maintenance strategy based on equipment defect state diagnosis and predictable results.

Early identification of defect states, defect state diagnosis and prediction of degradation degree, as well as decision optimization modeling are three key technological issues in the process. Early identification of defect state relies on status monitoring on the basis of sensor technology and defect occurrence time identification technologies modeling using Hidden Markov Model, stochastic filtering, and other theories. Defect state diagnosis and degradation degree prediction can serve as a scientific reference for preparing specific maintenance schemes, the solutions of which mainly include Short-time Fourier Transform, wavelet transform, and analysis and processing of other status monitoring data, as well as artificial neural network methods, expert system, finite element methods, and other equipment status prediction modeling methods. Decision optimization modeling is the core section of status maintenance decision. By integrating maintenance expenses and other economic factors, according to certain optimization targets, such as minimum expectation value of shutdown time, minimum expectation value of maintenance expenses within unit time, and maximum expectation value of system availability etc., the respective decision optimization models can be established.

Research on optimum status-based maintenance strategy mainly covers mechanics, management, mathematics, automation, computer science, and other disciplines; it is an emerging frontier hotspot.

1.8 Multi-objective particle swarm optimization

The particle swarm optimization algorithm was derived from detailed research on the foraging behaviors of birds; by utilizing an information sharing mechanism, it enables individuals to learn about each other's experiences in order to promote the development of the population. The particle swarm optimization algorithm is a method that applies evolutionary algorithms to obtain a group of candidate solutions and uses them to solve problems; its advantages include simple concepts, low optimization requirement, high solving speed, and strong global searching ability; it is a relatively new heuristic algorithm. The particle swarm optimization algorithm can be divided into three research directions: convergence analysis, practical application, and theoretical optimization. Multi-objective particle swarm optimization is subject to theoretical optimization. The improvement of a subtarget may cause degradation in the performance of another or several other subtargets. Thus, multi-objective optimization aims at coordinating and searching for a compromise among various subtargets in order to obtain a group of optimum solutions without pros and cons; then, a choice can be made artificially. In reality, multi-objective optimization corresponds more to decision-making activities; by utilizing the particle swarm optimization algorithm, it can clearly, simply, and efficiently solve multi-objective optimization issues. Presently, the research on multi-objective the particle swarm optimization algorithm is mainly concentrated on the efficiency of the particle swarm optimization algorithm, multi-objective optimization technology, and improvement of special issues. In terms of the algorithm mechanism improvement, the research is mainly focused on solving the self-adaptive particle swarm algorithm with evolving and changing algorithm parameters, solving a discrete particle swarm algorithm of discretization issues, and solving a fuzzy particle swarm algorithm of fuzzy optimization issues; in terms of the multi-objective optimization mechanism, the research is mainly focused on the selection of non-dominated solutions, trimming of external file sets, maintaining the diversity of non-inferior solution sets, as well as reasonable selection of the globally optimal solution, gbest, and individually optimal solution, pbest.

1.9 Bicycle sharing system

The concept of a bicycle sharing system was proposed in the 1960s. However, until the end of the 1990s, there were only a few cities that had offered bicycle sharing services. Along with global warming, more and more serious environmental pollutions, and the sharp rise of traffic pressure brought by rapid development of automotive transportation in the city, sustainable development has been gradually emphasized by various countries. As a green and environmentally friendly travelling mode, sharing bicycles has become more and more popular.

Sharing bicycles means to provide bicycles for people to use and park at stop points under self-service. It features flexibility and mobility, and can extend the capacity of public transit, alleviate traffic jams, and reduce fuel usage and pollutant emission. The reasons for individuals to use shared bicycles, service conditions of shared bicycles, user preferences, and the influences of shared bicycle usage on individuals and the society have already aroused broad concerns. The key issues in current research include operational management, vehicle allocation, vehicle maintenance and care, rental point layout and scheduling, route carrying capacity, system scale, and other scientific issues. On the basis of multiple integrated algorithms, such as static scheduling optimization algorithm, NP-hard and heuristic algorithms (such as taboo search algorithm, genetic algorithm, simulated annealing, and Ant Colony algorithm, among others), researchers and administrators verify optimization models that are established by the multi-objective dynamic layout and adapt them to urban features through the simulation platform. This research aims to solve mixed integer linear programming issues on the basis of logistics representation and branch cutting methods, and finding feasible solutions in the original grid plan; it aims at intensifying the slackness of linear programming issues on the basis of Benders decomposition, and solving capacity issues on the basis of routes of vehicles. The future development trend is to enhance public transit integration by combining the global positioning system (GPS), E-Bike platforms, Dockless systems, and other sharing systems, while driving statistical analyses of user quantities and research on targets such as frequency and routes.

Research on bicycle sharing systems mainly covers economics, transportation, information technology, automobile industry, and other disciplines; it has interdisciplinary features and is an emerging frontier hotspot.

1.10 Tradable electronic right-of-way mechanism

Tradable electronic right-of-way mechanism is a new scheme of urban congestion governance that draws lessons from the emission exchange mechanism in the environmental field, under which, the government distributes the right-of-way in the form of electronic waybills to all qualified citizens at the beginning of each period free of charge, and collects diversified electronic waybills on vehicles travelling on different road sections at different periods of time according to congestion levels of the road. Citizens are allowed to freely decide their travelling mode and route according to the deduction standard of waybills, and sell excessive electronic waybills to other road users in need through a government-supervised transaction platform. Under such a tradable electronic right-of-way mechanism, based on the scientific summarization of waybills and deduction scheme design according to different road sections and periods of time, the government is capable of effectively managing and controlling overall traffic, guiding travelers in their selection of travelling hours and routes, and achieving congestion governance effects that are the equivalent to the optimum congestion charging scheme. Nowadays, with the gradual perfection of mobile internet technology, GPS, wireless telecommunication technology, as well as information and transaction platform management technology, this scheme has a high level of feasibility.

Current research has discussed static equilibrium and evolutionary processes of dynamic flow and price under the specified tradable electronic right-of-way mechanism; tradable electronic right-of-way mechanism design under the premises of homogenous and heterogeneous users, demand function information shortage and transaction costs; mixed scheme design of tradable electronic right-of-way mechanism, road tolling, and other mechanisms; and extended applications in parking space allocation and other fields similar to the tradable right mechanism. In order to further propel the implementation of the mechanism, it will be necessary to solve other issues in the future, such as how to ensure fairness of the initial allocation of electronic waybills, how to determine the distribution and usage period of electronic waybills in a reasonable manner, and how to more precisely define the prices of electronic waybills and the dynamic evolutionary process of road traffic flow through simulation.

2 Understanding of engineering research focus

2.1 Fuzzy group decision method

Decisions can be universally found in various economic, political, and social fields. With the rapid development of science and technology, knowledge and information have exploded, prompting the emergence of various kinds of intricate and complex decision issues. More and more decision issues simultaneously contain quantitative and qualitative indicators, which contribute to the formation of complicated multi-attribute decision issues. With the development of decision theories in recent years, fuzzy group decision has become the new hotspot that arouses people's concerns. It has extensive theoretical research significance and actual background in terms of military affairs, economy, management, and system engineering. Although the research on fuzzy group decision has already obtained certain achievements, in terms of theoretical and practical applications, it still urgently requires further profound research.

A deeper analysis is carried out below by mainly focusing on how to aggregate the preferences of various subjects and form group preferences, how to sort out alternative schemes according to their attributes, and the fuzzy decision information measure theory in group decision processes.

2.1.1 Fuzzy information aggregation method research

As for the decision of fuzzy information, researchers normally apply aggregation operators, and aggregate multi-dimensional fuzzy decision information into an individual value; then, decision information aggregation values of alternative schemes are sorted out, so that the decision maker could analyze the decision. Thus, aggregation operators play an important role in the decision process of fuzzy information.

The most mature aggregation operator in current research is the ordered weighted averaging operator proposed by Yager in 1988, the function of which is to sort out evaluation information, then weight and aggregate the information according to the sorting position. Research hotspots in fuzzy information aggregation methods mainly include: the respective aggregation operators based on expression means of different fuzzy information, such as intuitionistic fuzzy set, hesitant fuzzy set, and fuzzy language; extending the existing ordered weighted averaging operator into more generalized aggregation operators; and the research on exchangeability, idempotence, monotonicity, and other expected properties of these aggregation operators. Currently, the research on intuitionistic fuzzy set aggregation operators is more mature; while research on hesitant fuzzy sets and semantics fuzzy information have been rarely seen. These areas have greater scope for further research and development.

2.1.2 Fuzzy decision information measure theoretical research

The important role of measure theory in fuzzy decision methods is mainly embodied in distance and similarity measurement of fuzzy information; it serves as the foundation of numerous decision methods. Distance and similarity indicators are mainly used for measuring the distance and similarity of data.

This research can be generally divided into distance measurement on the basis of the traditional Euclidean distance and Hamming distance, and distance measure on the basis of ordered weighted distance, mixed weighted distance, and weighted distance operator measurement of fuzzy ordered weighted distance, as well as information entropy theory. Theoretical research hotspots in fuzzy decision information measure mainly include the research on expanding distance measurement to fuzzy decision, intuitionistic fuzzy decision, interval intuitionistic fuzzy decision, and hesitant fuzzy decision; the research on a series of distance and similarity measurement methods for intuitionistic fuzzy information and interval intuitionistic fuzzy information generated on the basis of weighted distance operator, Choquet integration and geometric distance model and other theories; and information measure method for relative entropy on the basis of intuitionistic fuzzy information and interval intuitionistic fuzzy information.

2.1.3 Research on fuzzy preference relation and the respective sorting method

Preference relation describes preference information on decision issues when decision makers express targets, such as attributes or principles; by comparing the relations of every pair of targets, all targets can be sorted.

Fuzzy preference relation in the existing research is relatively mature. The core principle is to hopefully use membership and non-membership functions that take arbitrary values in the unit closed interval [0,1] to express a decision maker preference relation of two different targets. The research hotspots in this field mainly include: using interval intuitionistic fuzzy preference matrix to solve the problem of conditional information being insufficient under the background of an interval intuitionistic fuzzy set; the research on consistency of an individual preference and commonness of the group preference relation in order to solve the problem of an individual preference relation being inconsistent or the problem of group preference relation being incompatible by focusing on limited personal capabilities of the decision maker and fuzziness of the subject; the research on how to use consistency indicators of some generalized ordered weighted averaging operators to reflect the interval fuzzy preference relation; and how to characterize the preference relation with an unknown expert weight.

2.1.4 Present status of development and future development trends

When sorting alternative schemes, the decision maker mainly relies on the aggregation method to aggregate multi-dimensional fuzzy decision information into an individual value and uses it as the reference during sorting. Thus, research on the aggregation method under multiple fuzzy information forms has become a current research hotspot. Researchers extend the case on the basis of the existing ordered weighted averaging operator and obtain many generalized aggregation operators, as well as defining the algorithm and researching expected properties of aggregation operators; more and more decision issues contain quantitative indicators and qualitative indicators at the same time, which contribute to the formation of complicated multi-attribute decision issues. Based on these issues, the researchers propose an interval ladder-shaped fuzzy number multi-attribute group decision method, triangular number, intuitionistic fuzzy number, interval intuitionistic fuzzy number, hesitant triangular fuzzy information, and fuzzy number intuitionistic fuzzy information multi-attribute group decision method, and direct fuzzy number form multi-attribute group decision method; in order to solve various problems in the decision process, such as decision information fuzziness, undetermined weight and multiple criteria, researchers have proposed multiple decision methods, such as multi-criteria interval intuitionistic fuzzy decision methods, using Hamming distance and an adequacy coefficient in the decision method to parameterize the decision maker preference information, measuring weight of the decision maker under the background of interval intuitionistic fuzzy decision information provided by the decision maker, and determining weights of decision makers based on personal decisions by applying and promoting the technique for order preference by similarity to an ideal solution (TOPSIS) method in the form of an interval number.

Chinese experts and scholars have made achievements in terms of research on fuzzy decision information aggregation methods, theoretical research on fuzzy decision information measure, fuzzy preference relations, and the respective sorting methods, proposed many kinds of fuzzy group decision methods, and made great contributions to fuzzy group decision research.

This hotspot mainly covers mathematics, economics, automation, decision-making, industry economy, computer science, and the like, and is a profound hotspot of traditional research.

2.1.5 Major countries and institutions researching fuzzy group decision methods

The top 3 countries in terms of the number of core papers on the engineering research focus “Fuzzy group decision method” were China, Spain, and USA (Table 2.1.1); the top 3 countries or regions in terms of the average citation frequency of core papers were Taiwan of China, Spain, and China (Table 2.1.1). According to the collaboration network of major producing countries or regions of core papers (Figure 2.1.1), among the top 6 countries in terms of the number of papers, China, USA, and Spain had the most cooperation.

The top 3 institutions in terms of number of core papers were University Barcelona, Chongqing University of Arts and Sciences, and Anhui University (Table 2.1.2). According to the collaboration network of the top 10 institutions producing core papers (Figure 2.1.2), Ohio State University, Anhui University, and University Barcelona had the most cooperation.

During the period from 2011 to 2016, China published 28 core papers on the engineering research focus “Fuzzy group decision method” (Table 2.1.1). The Chinese mainland institutions that published more core papers were Chongqing University of Arts and Sciences and Anhui University (Table 2.1.2).

China and Spain had the most achievements in this research hotspot, with relatively high average citations, and were both in the leading position; USA and Canada made partial research. China had partnerships with all these countries. Different research institutions of various countries have cooperation with each other, and formed many cooperative sub-networks.

According to the analytic results, University Barcelona of Spain, Chongqing University of Arts and Sciences, and Anhui University of China made major contributions in this research hotspot. The research achievements of these three institutions accounted for 75% of total number (Table 2.1.2).

2.2 Service platform and enterprise information system based on the Internet of Things

The concept of the Internet of Things was originally derived from the network radio frequency identification system proposed by the Massachusetts Institute of Technology of USA in 1999. In 2005, the concept of the "Internet of Things" was officially defined during the World Summit on the Information Society held by the International Telecommunication Union in Tunis. The Internet of Things, in a narrow sense, refers to the network that connects different objects and is capable of realizing intelligent identification and management of objects; in a broad sense, the Internet of Things can be deemed as the integration of the information space and physical space that digitalizes and cyberizes everything, realizes highly efficient information interaction modes between objects, between objects and humans, as well as between humans and the real environment, and integrates various information technologies with social behaviors through new service modes, such that informatization can reach a higher perspective via comprehensive applications within human society. The service platform realizes encapsulation, combination, disassembly, transmission, follow-up, and interaction of information in the product life cycle management by utilizing an abstract information model, so as to offer information support for data integration and

Table 2.1.1 Major producing countries or regions of core papers on the engineering research focus "Fuzzy group decision method"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	China	28	70.0%	1306	66.80%	46.64	6	0
2	Spain	13	32.5%	662	33.86%	50.92	1	2
3	USA	4	10.0%	147	7.52%	36.75	1	0
4	Taiwan of China	2	5.0%	112	5.73%	56.00	0	0
5	Canada	2	5.0%	73	3.73%	36.50	1	0
6	England	1	2.5%	16	0.82%	16.00	0	0

Table 2.1.2 Major producing institutions of core papers on the engineering research focus "Fuzzy group decision method"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Univ Barcelona	13	32.5%	662	33.86%	50.92	1	2
2	Chongqing Univ Arts & Sci	11	27.5%	572	29.26%	52.00	3	0
3	Anhui Univ	6	15.0%	231	11.82%	38.50	1	0
4	Ohio State Univ	3	7.5%	111	5.68%	37.00	1	0
5	Cent S Univ	2	5.0%	128	6.55%	64.00	1	0
6	Guangdong Ocean Univ	2	5.0%	79	4.04%	39.50	0	0
7	Tianjin Univ	2	5.0%	73	3.73%	36.50	0	0
8	Zhejiang Wanli Univ	2	5.0%	64	3.27%	32.00	0	0
9	Shandong Econ Univ	1	2.5%	80	4.09%	80.00	1	0
10	Chang Gung Univ	1	2.5%	69	3.53%	69.00	0	0

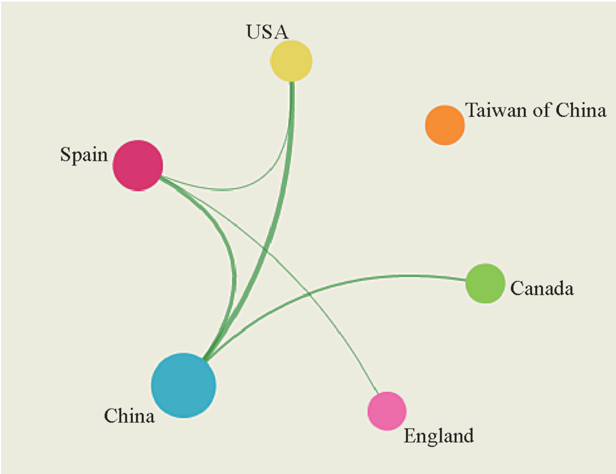

Figure 2.1.1 Collaboration network of major producing countries or regions of core papers on the engineering research focus "Fuzzy group decision method"[1]

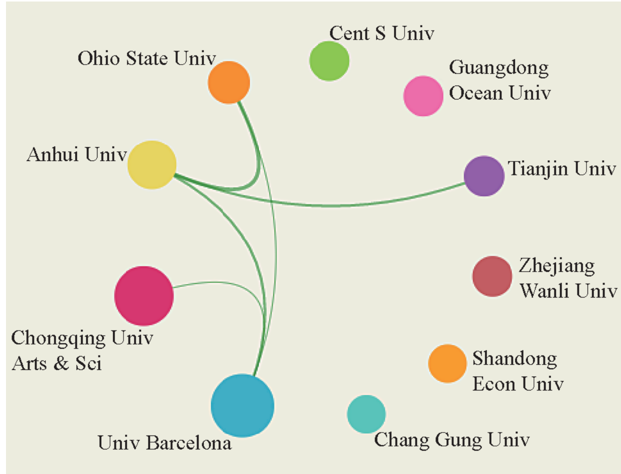

Figure 2.1.2 Collaboration network of the major producing institutions of core papers on the engineering research focus "Fuzzy group decision method"

intelligent interaction. An enterprise information system is an arbitrary information system that integrates and improves enterprise operation flow functions; it is capable of handling a large quantity of data, so as to support large and complex organizations or enterprises. The Internet of Things is deemed as a major opportunity for the development and reform of the information field. Service platforms and enterprise information systems based on the Internet of Things are capable of supporting the application of flexible and configurable modes that cover unified management of distributed and heterogeneous product data at different stages of the life cycle.

Service platform and enterprise information system based on the Internet of Things includes five frontier branch programs, namely cloud manufacturing service system based on the Internet of Things, enterprise cloud service architecture, enterprise information system architecture analysis, framework of emergency response decision support system, and configurable information service platform based on the Internet of Things.

2.2.1 Cloud manufacturing service system based on the Internet of Things

In the cyberized manufacturing period, operation mode, and manufacturing resource sharing and allocation, the intelligent access of terminal physical equipment, safety solution technologies and means are not complete. Cloud computing can change the service mode; cloud safety is able to solve safety concerns of cyberized manufacturing; by integration with the technological development of the Internet of Things, cloud manufacturing is able to solve complex manufacturing problems and carry out large-scale collaborative manufacturing. Cloud manufacturing is a service platform that utilizes network and cloud manufacturing; it is a new mode of cyberized manufacturing that organizes internet manufacturing resources (manufacturing cloud) based on user demand and offers various manufacturing services as needed. Compared with informatized manufacturing technology, there are five more prominent technical features for the integration of cloud manufacturing with the Internet of Things, including instrumentation of manufacturing resources and capabilities, virtualization, servitization, collaboration, and intelligentization; furthermore, it is capable of solving 10 major categories of key technologies, including general technology, resource awareness and access technology, resource capability virtualization and servitization technology, virtual cloud manufacturing service environment construction and management technology, virtualization cloud manufacturing service environment operation technology, virtualization cloud manufacturing service environment evaluation technology, cloud manufacturing reliability and safe manufacturing service technology, cloud manufacturing universally applicable man–machine

[1] In the figure, the nodes refer to the countries or regions, the size of the nodes refers to number of papers, the connecting line between nodes refers to papers published based on research cooperation, and the thickness of the connecting line indicates the number of papers based on research cooperation. These are the same in full text.

interaction technology, cloud manufacturing service platform application technology, and informatized manufacturing technology. Currently, the cloud manufacturing service system based on the Internet of Things is under construction. Various countries have also attached great importance to the cloud manufacturing industry.

2.2.2 Enterprise cloud service architecture

IT service in the modern enterprise requires a higher level of flexibility, expansibility, and cost advantage. Enterprise cloud services offer on-demand and expandable computing services. The architecture of enterprise cloud services aims at integrating IT resources in the enterprise and creating an operable standard-based service, such that it can be re-assembled and applied. Cloud services are subject to the addition, usage, and delivery mode of relevant services based on the Internet. They normally involve the provision of dynamic resources, which can easily be expanded and which are normally virtualized through the Internet. Cloud services can be divided into infrastructure service, software service, and platform service. By utilizing cloud service, it is possible to realize fast access to service, lower prophase costs and investment, and flexible payment mode. Presently, there are five trends for the development of enterprise cloud service architecture: ① develop service level agreement sensing enterprise cloud service architecture; ② develop special enterprise cloud service for SMEs; ③ develop universal cloud service interface; ④ prepare evaluation criteria and decision support tools; ⑤ conduct enterprise cloud migration factor investigation.

2.2.3 Enterprise information system architecture analysis

Information system architecture is an architecture that reflects the relationship among various components of the information system of the government, enterprise, or institution, as well as the relationship between the information system and the relevant business, and the relationship between the information system and relevant technologies, which refer to the definition of the respective choices in application programs, technologies, data, and the investment portfolio, as well as configurations of hardware, software and communications. There are many advantages for the enterprise information system architecture; for instance, it is capable of offering a more sensitive system to the enterprise; better reusing existing IT assets of the enterprise; reducing development costs and increasing reuse; offering more complete integration to the entire system; considering each application as a service, so as to promote sharing and fundamentally solving the problem of "information islands". Decision makers of the enterprise only need to prepare the flow according to management-level strategies of the enterprise; while the variation of IT system only needs to consider business applications as service modules for instant usage without putting too much thought on architectural approaches and realization details of the bottom layer. There are also certain problems for the information system architecture: ① safety cannot be fully ensured; ② purposefulness of the information system architecture is not strong; ③ research on principles of the information system architecture is insufficient. Presently, there is no book related to the research on information system architecture technologies; and dissertations are mostly related to applications of existing or mature technologies in certain fields. When selecting a software structural system for the enterprise information system, it is necessary to consider multiple quality attributes that often generate conflicts.

2.2.4 Framework of emergency response decision support system

An emergency response decision support system needs to assist decision makers to evaluate emergency plans and select an appropriate emergency plan in case of emergency, support heterogeneous emergency response data sources and offer proper emergency rescue knowledge for the decision maker. It also needs to offer differentiated services to satisfy requirements. Whether the system is effective depends on the framework it refers to. Emergency response decision support system is mainly applied in preparing the emergency early warning and emergency plan, coordinating and instructing emergency activities, managing resources, and offering relative knowledge. The framework of the emergency response decision support system mainly consists of e-government affairs, an information technical infrastructure library, and a decision feedback mechanism. The emergency response decision support system is an integral part of e-government affairs that supports government emergency response. Emergency response decisions involve organizations, departments, personnel, resources, and laws. The fundamental challenges for emergency response decisions are how to effectively deal with emergencies by using application programs of the emergency response decision support system, and how to satisfy victims in the emergency rescue process. Research on the emergency decision system framework can be divided into four aspects: ① core module that implements the emergency response decision support system; ② learn about the knowledge warehouse operation mechanism in the emergency decision support system through internet research of emergency schemes and suggestions; ③ apply new technologies in newly established industry information integration projects and the enterprise system, and develop the existing system into a highly integrated system; ④ integrate data mining, Internet of Things, particle swarm optimization, social networks, and other new technologies or conceptual systems to improve existing performances of the system.

2.2.5 Configurable information service platform based on the Internet of Things

Internet of Things software not only needs to process real-time and heterogeneous data, but also needs to support complex business applications, and support flexible and configurable modes. It is crucial for the unified management of distributed and heterogeneous product data that cover different stages of the life cycle. The configurable information service platform can offer information support for data integration and intelligent interaction, which is conducive for developing application programs based on the Internet of Things. The configurable and open application program software platform based on the Internet of Things covers the entire product life cycle, such that heterogeneous and distributed product information can be integrated into the internal organization of product manufacturing quantity management. The configurable information service platform based on the Internet of Things consists of three dimensions, namely life cycle, product structure, and information. It is capable of designing, developing, and executing enterprise application programs in the mobile environment, and comprehensively solving the problem of multi-layered product life cycle management.

2.2.6 Present status of development and future development trends

Current research on the Internet of Things mainly concentrates on object identification or event treatment; the research emphasis has been on the design and manufacturing. Most of the research does not have high-level comprehensive intelligent interactions; they lack complete information representations at various stages of product usage, care, and maintenance. The traditional enterprise information system is mainly realized on the architecture level; they are not able to flexibly adapt to changes and uncertainties. Product information only contains certain complete parameters, and the semantic relation among components is missing in the assembly process. While in the future, information and service platforms based on the Internet of Things will not only be able to support product life cycle management and realize seamless integration of heterogeneous data from different stages, but also be able to realize seamless integration of the semantic relations among these objects in order to support intelligent interaction.

This hotspot mainly covers computer science, economy, industry, telecommunication, automation, and the like, and is an emerging frontier hotspot.

2.2.7 Major countries and institutions researching the service platform and enterprise information system based on the Internet of Things

The top 3 countries in terms of the number of core papers on the engineering research focus "Service platform and enterprise information system based on the Internet of Things" were China, USA, and Thailand (Table 2.2.1). According to the number of core papers, China was essentially in the leading position. The top 3 countries or regions in terms of average citation frequency were Wales, USA, and England (Table 2.2.1). According to the Collaboration network of the major producing countries or regions of core papers (Figure 2.2.1), among the major countries or regions in terms of the number of papers, China and USA had the most cooperation.

The top 3 institutions in terms of the number of core papers were Old Dominion University, Chinese Academy of Sciences, and Shanghai Jiao Tong University (Table 2.2.2). According to the Collaboration network of the major producing institutions of core papers (Figure 2.2.2), University of Science and Technology of China, Shanghai Jiao Tong University, Chinese Academy of Sciences, and Old Dominion University had the most cooperation.

During the period from 2011 to 2016, China published 46 core papers on the engineering research focus

"Service platform and enterprise information system based on the Internet of Things" (Table 2.2.1). The major institutions that published more core papers were Chinese Academy of Sciences, Shanghai Jiao Tong University, and University of Science and Technology of China (Table 2.2.2).

2.3 Simulation-based medical teaching

Simulation-based medical teaching refers to integrating information, demonstration, and practical learning into medical teaching activities, and conducting knowledge and skill training through simulation means. Specific research in this field mainly focuses on medical care professional teaching practice activities. Research on simulation-based medical teaching covers simulation technologies and methods, design of the conceptual framework, research on task reporting, design and application of teaching practice activities, practical effect analysis and mechanism research, and clinical conversion of training achievements; it comprehensively applies medical simulation, training theory, empirical research, as well as theories and approaches of translational sciences.

Application of simulation in medical teaching can be

Table 2.2.1 Major producing countries or regions of core papers on the engineering research focus "Service platform and enterprise information system based on the Internet of Things"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Number of consistently cited papers	Patent-cited publications
1	China	46	92%	1657	81.87%	36.02	1	0
2	USA	44	88%	1864	92.09%	42.36	3	0
3	Thailand	5	10%	171	8.45%	34.20	0	0
4	England	4	8%	166	8.20%	41.50	0	0
5	Sweden	3	6%	71	3.51%	23.67	0	0
6	Wales	1	2%	86	4.25%	86.00	0	0
7	Poland	1	2%	36	1.78%	36.00	0	0
8	Taiwan of China	1	2%	26	1.28%	26.00	0	0
9	Scotland	1	2%	25	1.24%	25.00	0	0
10	Finland	1	2%	23	1.14%	23.00	0	0

Table 2.2.2 Major producing institutions of core papers on the engineering research focus "Service platform and enterprise information system based on the Internet of Things"

No.	Institution	Core papers	Proportion of Core Papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Number of consistently cited papers	Patent-cited publications
1	Old Dominion Univ	43	86%	1850	91.40%	43.02	3	0
2	Chinese Acad Sci	30	60%	1131	55.88%	37.70	0	0
3	Shanghai Jiao Tong Univ	22	44%	740	36.56%	33.64	0	0
4	Univ Sci & Technol China	17	34%	552	27.27%	32.47	0	0
5	Beihang Univ	7	14%	314	15.51%	44.86	0	0
6	Indiana Univ Purdue Univ	7	14%	261	12.90%	37.29	0	0
7	Chulalongkorn Univ	5	10%	171	8.45%	34.20	0	0
8	Northeastern Univ	4	8%	178	8.79%	44.50	0	0
9	Corp Res	3	6%	71	3.51%	23.67	0	0
10	ABB	3	6%	71	3.51%	23.67	0	0

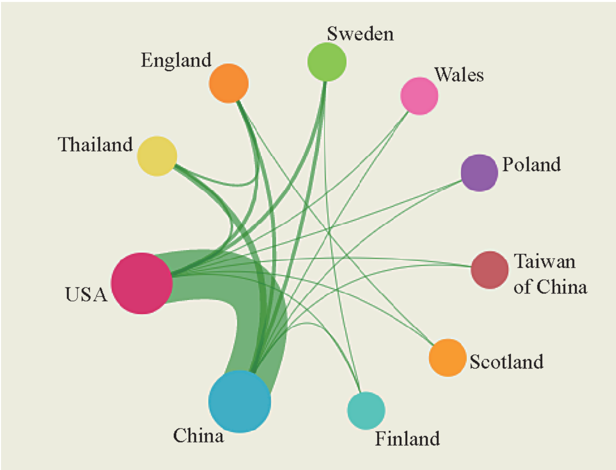

Figure 2.2.1 Collaboration network of the major producing countries or regions of core papers on the engineering research focus "Service platform and enterprise information system based on the Internet of Things"

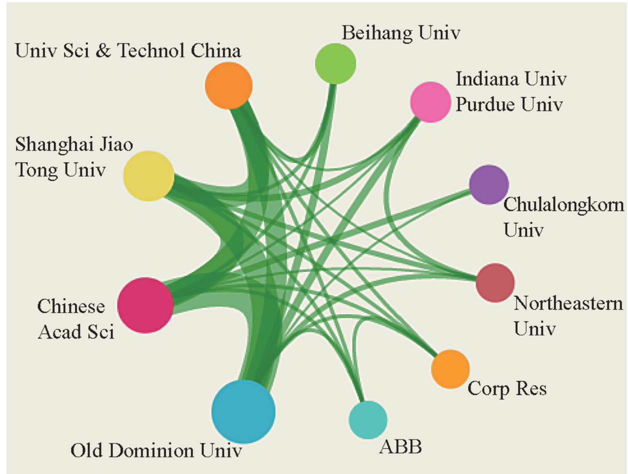

Figure 2.2.2 Collaboration network of the major producing institutions of core papers on the engineering research focus "Service platform and enterprise information system based on the internet of things"

deemed as having been derived from flight simulation in the aerospace field. Traditional medical teaching is similar to apprenticeship, in which apprentices are in an actual surgery operating environment with high risks at the beginning, and simulation-based medical teaching could offer apprentices a safe environment for skill training before conducting actual surgeries on patients. On the other hand, relevant research has demonstrated that, compared with classroom learning, simulation-based medical teaching has better training effects in learning clinical skills.

After decades of development, simulation-based medical teaching has already been widely applied in the medical field, covering numerous aspects from community hospitals to academic-type medical institutions, from students to medical experts, from clinical surgeries to team communications; it has been playing a significant role. A large number of works in the literature have fully demonstrated the training effects and significance of simulation-based medical teaching. As a traditional research hotspot, the current popular literature covers medical care, education, ergonomics, and psychology.

2.3.1 Mainstream of engineering science and branch engineering science

From the aspect of engineering science, the popular research on simulation-based medical teaching mainly includes medical care research and training research.

Medical care is subject to extensive disciplinary research that encompasses comprehensive care, physiotherapy, occupational therapy, health economics, and other disciplines. As an integral part of the medical care and service discipline, simulation-based medical teaching focuses on training knowledge and skills of health care personnel through simulation teaching, and finally improving their actual levels in medical care. The major concerns of the research include:

(1) Research on simulation teaching technologies and methods of medical teaching aimed at strengthening the scientific merit, flexibility, and authenticity of simulation through application of simulation tools and research on the simulation environment, so as to improve the effects of simulation-based medical teaching. This method emphasizes simulation technology innovation, and applies patient simulation using actors, physical human models, multi-media computer science systems, and standardized patients to medical teaching.

(2) With the help of idea of conversion research in medical research and development, clinical application of achievements of simulation-based medical teaching in reality is researched, including the design of teaching effect testing methods, how to improve conversion of training achievements, and how to apply simulation-based training methods in conversion research itself, and so on.

Training refers to expanding work-related knowledge, skills, and attitude of the trainee, and researching training tools, methods, strategies, and contents by applying systematic methods. As a practical application of training research in the medical field, major concerns of the research on simulation-based medical teaching include: ① comparing and demonstrating training effects of simulation-based medical teaching through designed experiments or meta-analysis; ② research learning theories and conceptual framework that are suitable for medical teaching from the aspect of training and use them to instruct the design of simulation-based medical teaching, such as cognitive load theory, group training theory, conceptual framework of simulation-based training, task reporting, and analysis of characteristics of learners, and so on; ③ research internal mechanism and design strategies of simulation-based medical teaching, and analyze medical teaching differences generated by different applications from programmed basic skills to complex surgeries. Current research mainly includes research on teaching personnel, cost-benefit ratio of medical teaching, simulation ability allocation, and auxiliary design of means for supporting various steps of training.

2.3.2 Present status of development and future development trends

Presently, research on simulation-based medical teaching is focused on simulation technologies and methods, learning theories and methods, practical applications, and conversion of training achievements. The current status of the development of relevant research mainly includes the following aspects:

(1) It is generally agreed that research on medical technology can be divided into three stages, including the upstream stage T1 (laboratory technology research), downstream stage T2 (clinical applications to patient-care), and stage T3 (applications being able to actually improve health of patients and the public). By extending this concept to the research on simulation-based medical teaching, it can be discovered that, most of the current research focuses on teaching methods and technologies (stage T1) of simulation teaching. In recent years, a minority of research has demonstrated feasibility of effects in clinical experiments (stage T2) and the improvement of the ultimate medical level (stage T3). Research thinking in the future has been expanded from research and development of simulation systems to clinical applications, namely how to test the actual effects of the simulation system, so as to select and smoothly operate the system; how to analyze the relationship among patients, technologies, medical care professions and organizational institutions through simulation; how to transform knowledge obtained from simulation into guiding principles for practical operations or practical teaching courses. This is also the major concern of most of popular papers in this analysis.

(2) Simulation-based medical teaching uses particularly established simulation centers as main training grounds, which are different from clinical practices and thus create the problem of conversion. Some research has started to focus on in-situ simulation, while integrating the actual clinical environment with the simulation. Currently, in-situ simulation has already made certain progress, but it is still mainly restrained by description of applications in partial fields, like surgeries, and a lack of comprehensive and systematic research.

(3) Current research mainly focuses on simulation technology and innovation, while neglecting the "human" factor. In other words, the research mainly surrounds technologies and methods of medical teaching and lacks a focus on teaching personnel. As the organizer and guide of medical teaching activities, teaching personnel exert major influences on medical teaching. Future research shall pay more attention to the functions of teaching personnel, such as characteristics and behaviors of teaching personnel, influences on teaching activities, and influences on the teaching personnel excitation mechanism.

(4) In existing empirical research, in terms of demonstrating effectiveness of training, researchers pay more attention to "whether it is effective," and seldom do they explore "why it is effective"; in addition, the experimental design mode that mainly consists of volunteers also lacks verification by actual clinical effects. Meanwhile, a large body of the existing research lacks comparisons with diversified existing methods.

(5) Some important steps of simulation training, especially the task reporting process, are emphasized by current research. A task report refers to an introspective discussion carried out by learners under the instruction of teaching personnel, which aims at discovering and making up defects appearing in teaching activities through discussions and strengthening the understanding towards knowledge and skills. Task reporting is an important step in the learning cycle. Several popular papers have

separately carried out studies in terms of the effectiveness, methods, strategies, and conceptual framework of task reporting, designing auxiliary means, and analysis of key problems. Current research on task reporting of simulation-based medical teaching still lacks a definite theoretical framework, and research on the respective internal mechanism and auxiliary means are not yet complete.

This hotspot mainly covers computer science, automation, telecommunication, biology, medicine, and the like, and is a profound hotspot of traditional research.

2.3.3 Key countries and institutions researching simulation-based medical teaching

The top 3 countries or regions in terms of the number of core papers on the engineering research focus "Simulation-based medical teaching" were USA, Canada, and England (Table 2.3.1); the top 3 countries or regions in terms of the average citation frequency were Switzerland, Belgium, and England (Table 2.3.1). According to the collaboration network of the major producing countries or regions of core papers (Figure 2.3.1), among the top 9 countries or regions in terms of the number of papers, England, Canada, and USA had the most cooperation.

The top 3 institutions in terms of the number of core papers were University Calgary, Mayo Clinical, and University Toronto (Table 2.3.2). According to the collaboration network of the major producing institutions of core papers (Figure 2.3.2), University Toronto, Mayo Clinical, University Calgary, and University British Columbia had the most cooperation.

These results have further reflected that, regardless of quantity or quality of papers, USA and Canada were both in the leading position. Furthermore, the production institutions of core papers mainly consisted of universities, according to which, it is believed that, universities have been the main force of current research; other research institutions are mainly hospitals and medical centers. Meanwhile, there was significant cooperation between researchers from universities and those from hospitals, which have also proved the concerns of the current research on clinical practices, emphasized above.

During the period from 2011 to 2016, China published 0 core papers on the engineering research focus "Simulation-based medical teaching".

The existing core papers are all from foreign researchers. There are significant differences currently in simulation-based medical teaching research between China and other countries. Compared with the comprehensive research of other countries from simulation teaching technologies to clinical applications, research in China is still at the relatively basic stage in all aspects. Especially that the actual clinical applications of simulation-based medical teaching still lack of powerful analytic demonstration and further research. In future research, China shall not restrain our visions on upstream simulation teaching methods and technologies themselves; instead, we shall start from actual circumstances and pay attention to how to more effectively improve downstream clinical applications.

Major producing countries or regions of citing core papers on the engineering research focus "Simulation-based medical teaching" were USA, Canada, Denmark, England,

Table 2.3.1 Major producing countries or regions of core papers on the engineering research focus "Simulation-based medical teaching"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	USA	23	67.65%	692	68.86%	30.09	6	1
2	Canada	12	35.29%	339	33.73%	28.25	1	0
3	England	4	11.76%	141	14.03%	35.25	1	0
4	The Netherlands	3	8.82%	84	8.36%	28.00	1	0
5	Denmark	3	8.82%	63	6.27%	21.00	0	1
6	Switzerland	2	5.88%	83	8.26%	41.50	0	0
7	Belgium	1	2.94%	39	3.88%	39.00	0	0
8	Brazil	1	2.94%	23	2.29%	23.00	1	0
9	Sweden	1	2.94%	15	1.49%	15.00	0	0

Table 2.3.2 Major producing institutions of core papers on the engineering research focus "Simulation-based medical teaching"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Univ Calgary	6	17.65%	181	18.01%	30.17	1	0
2	Mayo Clin	5	14.71%	155	15.42%	31.00	0	0
3	Univ Toronto	5	14.71%	73	7.26%	14.60	0	0
4	Northwestern Univ	4	11.76%	178	17.71%	44.50	0	0
5	Univ London Imperial Coll Sci Technol & Med	3	8.82%	69	6.87%	23.00	1	0
6	Univ British Columbia	3	8.82%	56	5.57%	18.67	0	0
7	Univ Hlth Network	3	8.82%	46	4.58%	15.33	0	0
8	McMaster Univ	2	5.88%	135	13.43%	67.50	0	0
9	Ctr Med Simulat	2	5.88%	82	8.16%	41.00	0	0
10	Harvard Univ	2	5.88%	82	8.16%	41.00	0	0

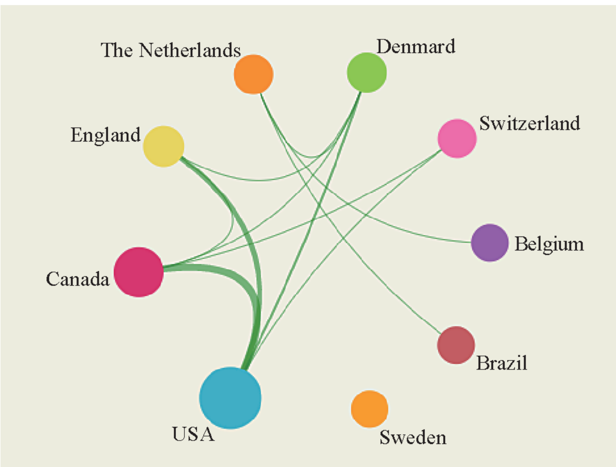

Figure 2.3.1 Collaboration network of the major producing countries or regions of core papers on the engineering research focus "Simulation-based medical teaching"

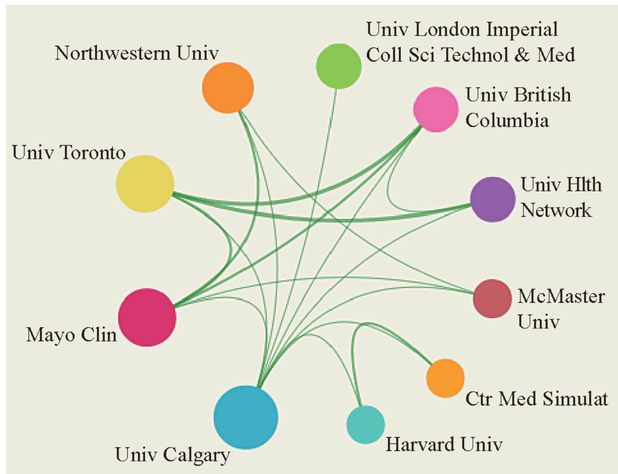

Figure 2.3.2 Collaboration network of the major producing institutions of core papers on the engineering research focus "Simulation-based medical teaching"

and Switzerland (Table 2.3.3); the major producing institutions of citing core papers were University Health Network, University Toronto, Ann & Robert H Lurie Children's Hospital Chicago, Loyola University Chicago, University Calgary, Northwestern University (Table 2.3.4). Based on the above, China was not in a leading position.

2.4 Multi-objective particle swarm optimization

Optimization issues universally exist in production and people's daily lives. In recent years, in order to solve these optimization issues, research works on optimization methods have emerged in large numbers. Although traditional optimization method theories based on mathematics planning are mature, there are multiple restrictions and shortcomings when solving optimization issues, such as curse of dimensionality, needs of a continuous and differentiable objective function and so on. Thus, in the past few decades, a swarm intelligence optimization method derived from the natural evolution process has been greatly developed, with the formation of a series of intelligent optimization algorithms. The particle swarm optimization algorithm has been widely researched and applied due to its clear definition, easy realization, and high solving efficiency. It is a global arbitrary search algorithm based on swarm intelligence, which was proposed after being inspired by migration and aggregation behaviors of birds in their foraging process. Ever since it was proposed, it has always been a hotspot of research on intelligent optimization algorithms. In 2002, Coello et al. proposed the multi-objective particle swarm optimization algorithm; later, the algorithm received great attention from scholars of relevant fields both at home and abroad, and research achievements emerged in an endless stream. The multi-objective particle swarm optimization algorithm has been widely applied to multi-objective optimization issues in fields like energy, chemical engineering, economy, bio-information and the like, such as redundancy allocation of multi-objective reliability, and reliability optimization; the minimum cost generation expansion in the electric system field, multi-objective reactive power optimization of electric system, electric system economic environment scheduling under multi-objective restrictions of the generator; multi-objective optimization of stock exchange decision geared to the maximum interests in the economy field, and oil field multi-objective model solving; genetic multi-objective clustering in the bio-information field, and multi-objective optimization of orthogonal immune clone.

Presently, research on the multi-objective particle swarm optimization algorithm mainly concentrates on efficiency of the particle swarm optimization algorithm, multi-objective optimization technology, and research on improvement of special issues. In terms of algorithm mechanism improvement, the research mainly concentrates on self-adaptive particle swarm algorithms that change with the evolution process for solving algorithm parameters, discrete particle swarm algorithms for solving discrete issues and fuzzy particle swarm algorithm for solving fuzzy optimization issues; in terms of the multi-objective optimization mechanism, the research mainly concentrates on selection of non-dominated solutions, trimming of external file sets, maintaining the diver-

Table 2.3.3 Major producing countries or regions of core papers that are cited by core papers on the engineering research focus “Simulation-based medical teaching”

No.	Country/Region	Number of core papers cited by core papers	Proportion	Mean year
1	USA	6	42.86%	2014.0
2	Canada	5	35.71%	2014.2
3	Denmark	1	7.14%	2015.0
4	England	1	7.14%	2015.0
5	Switzerland	1	7.14%	2013.0

Table 2.3.4 Top 10 institutions producing of core papers that are cited by core papers on the engineering research focus “Simulation-based medical teaching”

No.	Institution	Number of core papers cited by core papers	Proportion	Mean year
1	Univ Hlth Network	3	10.71%	2013.67
2	Univ Toronto	3	10.71%	2013.67
3	Ann & Robert H Lurie Childrens Hosp Chicago	2	7.14%	2015.00
4	Loyola Univ Chicago	2	7.14%	2014.00
5	Univ Calgary	2	7.14%	2013.50
6	Northwestern Univ	2	7.14%	2014.00
7	Alberta Childrens Prov Gen Hosp	1	3.57%	2015.00
8	ETH	1	3.57%	2013.00
9	Herlev Univ Hosp	1	3.57%	2015.00
10	Hosp Sick Children	1	3.57%	2014.00

Note: ETH stands for ETH Zurich.

sity of non-inferior solution sets, as well as reasonable selection of globally optimal solution gbest and individually optimal solution pbest.

2.4.1 Mainstream of engineering science and branch engineering science

Currently, research on the multi-objective particle swarm algorithm mainly concentrates on the efficiency of the particle swarm optimization algorithm, multi-objective optimization technology, and research on improvement of special issues. ① In terms of improving the global search ability and convergence speed of the particle swarm optimization algorithm, it mainly focuses on improvement of the particle swarm optimization algorithm itself, such as using a microhabitat and multi-population mode to improve the global search ability of the algorithm, reasonably selecting pbest and gbest to balance global search ability and convergence speed of the algorithm, dynamic self-adaptive confirmation of inertia weight, and integrating with other algorithms to improve search ability of the algorithm; ② In terms of multi-objective optimization technology, it mainly includes the research on scientifically and reasonably dominating, sorting, and reducing computational complexity, and the research on new external file set trimming technologies to improve the diversity and distributivity of the non-inferior solution set; ③ In terms of integrating with actual engineering applications, it mainly includes principal-subordinate analysis and hierarchical and layering research on the target by integrating with real situations of engineering applications, reducing dimension of the optimization target, lowering the complexity of algorithm solving, introducing expert knowledge to constrain the optimization space for decision variables and improve the convergence speed of the algorithm, and researching constraint handling method of the algorithm based on practical issues to improve the efficiency of algorithm solving. Generally speaking, most of the research of scholars in various countries on the multi-objective particle swarm optimization algorithm is carried out by integrating actual engineering issues while mainly aiming to solving actual engineering issues; algorithm research works, particularly on the theoretical level, can be hardly seen. This is also the key research issue which needs to be surmounted of the multi-objective particle swarm algorithm, as well as the future development trend.

2.4.2 Present status of development and future development trends

For over a decade, the multi-objective particle swarm algorithm has received widespread attention, with the publication of a large quantity of academic research papers and highly cited papers. Currently, it is still the hotspot of research in the multi-objective optimization field. Now, research on multi-objective particle swarm algorithm mainly centers on two aspects: ① algorithm mechanism improvement, such as self-adaptive particle swarm algorithm with parameters changing with the evolution process, discrete particle swarm algorithm for solving discrete issues, and fuzzy particle swarm algorithm for solving fuzzy optimization issues; ② as for the research on multi-objective optimization mechanisms, such as selection of non-dominated solutions, trimming of external file sets, maintaining the diversity of non-inferior solution sets, and reasonable selection of the globally optimal solution gbest and individually optimal solution pbest. By integrating with the current research condition analysis of the multi-objective particle swarm optimization algorithm, the future research trends include:

(1) Particle swarm topological structure research. Diversified particle swarm neighboring topological structures are simulations toward societies of different types, such as star connection, ring connection, and so on; by researching the scope of application of different topological structures, it is conducive for the extension and application of the particle swarm optimization algorithm.

(2) Theoretical research on the particle swarm algorithm. Current research on the algorithm mainly focuses on application research; parameters of the algorithm are normally selected by applying trial-and-error method based on experience, which still lacks theoretical instructions. Thus, it is necessary to further strengthen the theoretical research on the convergence speed, parameter robustness, and global convergence of the algorithm, including discussions on its characteristics under multi-objective and constrained conditions.

(3) Research on the mechanisms of the high-dimension multi-objective algorithm. While dealing with high-dimension multi-objective issues, computational complexity of the traditional multi-objective algorithm based on Pareto Sorting grows exponentially with the increase in the quantity of optimization targets, namely the Curse of Dimensionality exists. It is necessary to further develop a

more reasonable and highly efficient non-inferior solution sorting and selecting mechanism, which lowers temporal and spatial computation complexity without degrading the search performance.

This hotspot mainly covers automation, industry, computer science, telecommunication, aeronautics and astronautics, mathematics, mechanics, and the like, and is an emerging frontier hotspot.

2.4.3 Major countries and institutions researching multi-objective particle swarm optimization

The top 3 countries in terms of the number of core papers on engineering research focus of "Multi-objective particle swarm optimization" were Iran, France, and South Africa (Table 2.4.1); the top 3 countries in terms of the average citations were Mexico, South Africa, and France (Table 2.4.1). According to the collaboration network of the major producing countries or regions of core papers (Figure 2.4.1), among top 10 countries in terms of the number of papers, South Africa, France, Iran, and Mexico had the most cooperation.

The top 3 institutions in terms of the number of core papers were KN Toosi University, Islamic Azad University, and KN Toosi University of Technology (Table 2.4.2). According to the collaboration network of the top 10 producing institutions of core papers (Figure 2.4.2), KN Toosi

Table 2.4.1 Major producing countries or regions of core papers on the engineering research focus "Multi-objective particle swarm optimization"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Number of consistently cited papers	Patent-cited publications
1	Iran	27	69.23%	655	72.46%	24.26	1	0
2	France	9	23.08%	284	31.42%	31.56	0	0
3	South Africa	6	15.38%	210	23.23%	35.00	0	0
4	USA	5	12.82%	110	12.17%	22.00	0	0
5	China	5	12.82%	93	10.29%	18.60	0	0
6	India	4	10.26%	119	13.16%	29.75	0	0
7	Mexico	3	7.69%	127	14.05%	42.33	0	0
8	Israel	3	7.69%	64	7.08%	21.33	0	0
9	Malaysia	1	2.56%	29	3.21%	29.00	0	0
10	Turkey	1	2.56%	14	1.55%	14.00	0	0

Table 2.4.2 Major producing institutions of core papers on the engineering research focus "Multi-objective particle swarm optimization"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Number of consistently cited papers	Patent-cited publications
1	KN Toosi Univ	12	30.77%	355	39.27%	29.58	0	0
2	Islamic Azad Univ	11	28.21%	245	27.10%	22.27	0	0
3	KN Toosi Univ Technol	9	23.08%	276	30.53%	30.67	0	0
4	Univ Tehran	8	20.51%	182	20.13%	22.75	0	0
5	PUT	7	17.95%	154	17.04%	22.00	0	0
6	IRGCP	6	15.38%	210	23.23%	35.00	0	0
7	Univ KwaZulu Natal	6	15.38%	210	23.23%	35.00	0	0
8	ENSEM	6	15.38%	161	17.81%	26.83	0	0
9	Univ Massachusetts	4	10.26%	79	8.74%	19.75	0	0
10	IPN	3	7.69%	127	14.05%	42.33	0	0

Note: PUT stands for Petroleum University of Technology; IRGCP stands for Institut de Recherche en Génie Chimique et Pétrolier; ENSEM stands for Ecole Nationale Supérieure d'Electricité et de Mécanique; IPN stands for Instituto Politécnico Nacional.

University, KN Toosi University of Technology, University KwaZulu Natal, and IRGCP had the most cooperation.

During the period from 2011 to 2016, China published five core papers on engineering research focus of "Multi-objective particle swarm optimization". In this research hotspot, Iran was the country with an absolute advantage in the quantity of core papers; it was a leading country. France, South Africa, China, and USA also had higher quantities of core papers.

The major producing countries or regions of citing core papers on the engineering research focus "Multi-objective particle swarm optimization" were Iran, France, South Africa, China, and India (Table 2.4.3); the major producing institutions of citing core papers were separately University Tehran, KN Toosi University, Petroleum University of Technology (PUT), and KN Toosi University of Technology (Table 2.4.4). Based on the above, China was in a leading position.

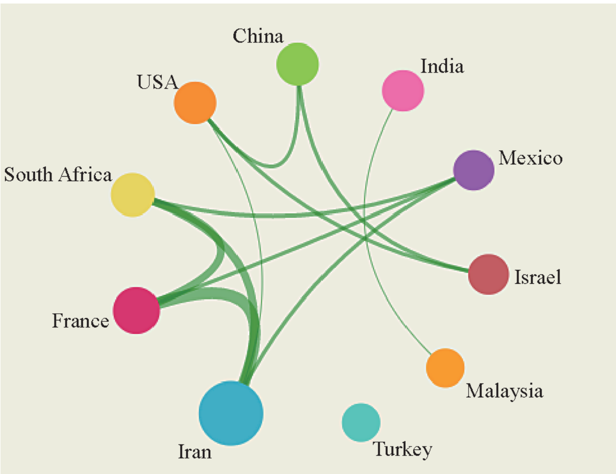

Figure 2.4.1 Collaboration network of the major producing countries or regions of core papers on the engineering research focus "Multi-objective particle swarm optimization"

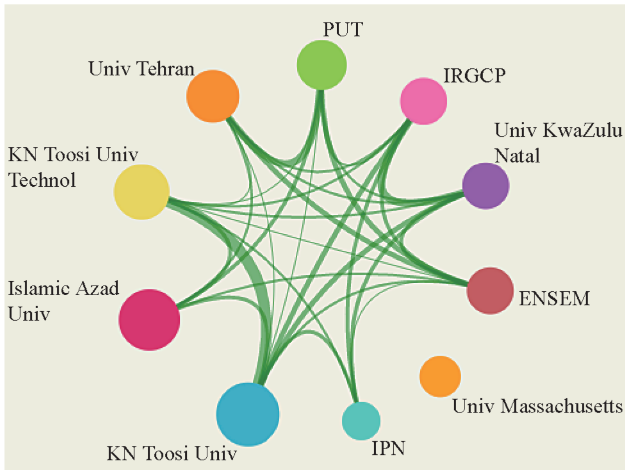

Figure 2.4.2 Collaboration network of the major producing institutions of core papers on the engineering research focus "Multi-objective particle swarm optimization"

Table 2.4.3 Major producing countries or regions of core papers that are citied by core papers on the engineering research focus "Multi-objective particle swarm optimization"

No.	Country/Region	Number of core papers cited by core papers	Proportion	Mean year
1	Iran	25	45.45%	2014.60
2	France	9	16.36%	2014.11
3	South Africa	5	9.09%	2013.40
4	China	4	7.27%	2013.75
5	India	3	5.45%	2014.00
6	Israel	2	3.64%	2013.50
7	Mexico	2	3.64%	2013.00
8	USA	2	3.64%	2013.50
9	Australia	1	1.82%	2014.00
10	Malaysia	1	1.82%	2013.00

Table 2.4.4 Major producing institutions of core papers that are cited by core papers on the engineering research focus "Multi-objective particle swarm optimization"

No.	Institution	Number of core papers cited by core papers	Proportion	Mean year
1	Univ Tehran	11	11.11%	2014.91
2	KN Toosi Univ	10	10.10%	2014.10
3	PUT	9	9.09%	2014.89
4	KN Toosi Univ Technol	8	8.08%	2014.38
5	ENSEM	7	7.07%	2014.43
6	Islamic Azad Univ	7	7.07%	2015.00
7	IRGCP	5	5.05%	2013.40
8	Univ KwaZulu Natal	5	5.05%	2013.40
9	Imam Khomeini Int Univ	4	4.04%	2015.00
10	Petr Univ Technol	4	4.04%	2015.25

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Chapter 3 National Performance

In Chapter 2, we deciphered and analyzed in detail the engineering research hotspots in nine fields and the engineering development hotspots in eight fields. This chapter describes the overall performance of engineering research and engineering development hotspots in different countries or regions by quantifying the contributions of leading countries or regions to these engineering research and development hotspots by the number of hotspots they dominate.

1 Overall comparison of the performance of the top 10 countries or regions in engineering research hotspots

The core papers on hotspots in engineering research are retrieved by Clarivate Analytics from the top 10% of the highly cited papers in each year in the Core Collection of Web of Science. There are 12 644 core papers, divided into 294 candidate hotspots. Based on data analysis, academicians and experts in related fields have selected about 10 engineering research hotspots for each field through professional judgment, resulting in 89 hotspots in total. The core papers in engineering research hotspots have relatively strong innovations, so to a certain extent, they reflect their leading role in engineering research. Ranking based on the first authors of the hotspot core papers can roughly be used to evaluate the leading performance of a nation or region.

Table 1.1 describes the statistical results of the top 10 countries or regions based on the number of core papers. The 10 countries or regions are ranked in accordance with the number of participating hotspots, where China's data does not include Taiwan of China, and England's data does not include Scotland and Northern Ireland. As shown, the first author core papers from the USA are distributed in all nine fields and in 78 engineering research hotspots. The leading performance of the USA is close to 88% in engineering research. It ranks first among 30 engineering research hotspots, accounting for 33.7% of hotspots, and ranks in the top 3 out of 50 hotspots, accounting for 56.2% of hotspots. The USA ranks first in all three statistical indicators. China's first author core papers are distributed in 66 hotspots, accounting for 74.2% of hotspots. It ranks first among 29 hotspots, accounting for 32.6% of the total, approaching the USA. It ranks in the top 3 out of 42 hotspots, accounting for 47.2%. China's overall performance is slightly lower than the USA, but clearly ahead of other

Table 1.1 Top 10 countries or regions based on the number of first author core papers

Country/Region	Participation			First place			Top 3		
	Number of hotspots	Proportion	Number of fields	Number of hotspots	Proportion	Number of fields	Number of hotspots	Proportion	Number of fields
USA	78	87.6%	9	30	33.7%	9	50	56.2%	9
China	66	74.2%	9	29	32.6%	8	42	47.2%	8
England	50	56.2%	9	0	0%	0	19	21.3%	7
Germany	43	48.3%	9	2	2.2%	2	16	18.0%	8
Australia	37	41.6%	9	3	3.4%	2	17	19.1%	6
Italy	38	42.7%	9	3	3.4%	3	8	9.0%	5
Korea	30	33.7%	8	3	3.4%	3	10	11.2%	6
Japan	30	33.7%	8	3	3.4%	3	7	7.9%	5
Iran	18	20.2%	8	4	4.5%	4	7	7.9%	6
Algeria	5	5.6%	4	2	2.2%	2	2	2.2%	2

countries or regions.

Core papers that cite other core papers can reflect how the techniques, data, and theories presented in the core papers have been further advanced after publication. Therefore, Core papers that cite other core papers track key discoveries, pay attention to cutting-edge developments, and play a potential leading role in future advances. The rank of a country or region, based on the number of hotspots covered by its first author citing core papers, can be used to identify its potential leading performance.

Table 1.2 shows the statistical results for the top 10 countries and regions determined by the number of first author citing core papers, which are ordered according to the number of participating hotspots. This table shows that citing core papers from the USA participate in the most hotspots, followed by China, Germany, Australia, and Japan. In particular, Spain, Taiwan of China, and Singapore perform well in terms of potential leading performance in engineering research hotspots, while Korea, England, and Italy are not in the top ten. From the number of participating hotspots of the core papers that cite other core papers, the number of first place hotspots and the number of top 3 hotspots, China and the USA perform comparably, and these two countries are far ahead of other countries or regions in all three indicators. Compared to Table 1.1, China has shown a very strong follow-up development capability in engineering research. Singapore and Taiwan of China also show a good trend of development, while Korea, England, and Italy rank 11, 12, and 13, respectively.

2 Overall comparison of the performance of the top 10 countries or regions in engineering development hotspots

Table 1.3 shows the statistical results for the top 10 countries or regions based on the number of first patentees of the core patents in the engineering development hotspots. Among them, China's data does not include Taiwan of China. The data demonstrates that the core patents of the first patentee in the USA, China, Japan, Korea, Germany, Canada, UK, Switzerland, France, and the Netherlands are distributed in all eight fields and involved in all 79 engineering development hotspots.

In addition, of the 79 engineering development hotspots, sixty-five are led by the USA, which are distributed in eight fields and account for 82.3% of all hotspots; fourteen are led by China, which are distributed in three fields and account for 17.7% of all hotspots; and no other countries or regions rank the first place in any hotspot. Concerning the top 5 countries or regions in any hotspot, the USA' and China's development hotspots are involved in eight fields and all 79 hotspots, while Japan's are involved in 73 hotspots belonging to eight fields, far ahead of other countries or regions.

Table 1.2 Top 10 countries or regions based on the number of core citing papers

Country/Region	Participation			First place			Top 3		
	Number of hotspots	Proportion	Number of fields	Number of hotspots	Proportion	Number of fields	Number of hotspots	Proportion	Number of fields
USA	65	73.0%	9	25	28.1%	8	44	49.4%	9
China	59	66.3%	9	25	28.1%	9	42	47.2%	9
Germany	32	36.0%	9	3	3.4%	3	15	16.9%	7
Australia	30	33.7%	9	4	4.5%	4	15	16.9%	7
Japan	22	24.7%	8	4	4.5%	4	10	11.2%	5
Spain	21	23.6%	7	1	1.1%	1	5	5.6%	3
Singapore	16	18.0%	7	0	0%	0	7	7.9%	5
Iran	14	15.7%	7	5	5.6%	5	10	11.2%	6
Taiwan of China	12	13.5%	7	2	2.2%	2	3	3.4%	2
Algeria	4	4.5%	4	1	1.1%	1	2	2.2%	2

Table 1.3 Top 10 countries or regions based on the number of first patentees

Country/Region	Participation			First place			Top 5		
	Number of hotspots	Proportion	Number of fields	Number of hotspots	Proportion	Number of fields	Number of hotspots	Proportion	Number of fields
USA	79	100%	8	65	82.28%	8	79	100%	8
China	79	100%	8	14	17.72%	3	79	100%	8
Japan	79	100%	8	0	0.0%	0	73	92.41%	8
Korea	79	100%	8	0	0.0%	0	46	58.23%	8
Germany	79	100%	8	0	0.0%	0	45	56.96%	7
Canada	79	100%	8	0	0.0%	0	39	49.37%	8
UK	79	100%	8	0	0.0%	0	19	24.05%	5
Switzerland	79	100%	8	0	0.0%	0	5	6.33%	1
France	79	100%	8	0	0.0%	0	5	6.33%	3
Netherland	79	100%	8	0	0.0%	0	3	3.80%	2

3 Relationship between research hotspots

A relationship between engineering research hotspots can be characterized by mutual citations between hotspots' core papers. Figure 3.1 illustrates the citation network of the 89 engineering research hotspots, where the nodes represent hotspots, the node size represents the number of core papers in the hotspot, and hotspots with the same color belong to the same field. Two nodes are connected if there is at least one citation between the papers in two hotspots. The weight of a link is defined by the count of citations between two nodes.

We can observe two characteristics from the figure. First, the core papers in the field of medical and health do not cite the core papers in other fields, nor are they cited by other fields. Second, there are more links between hotspots than within hotspots. Intra-field connections are natural manifestations of the inner relations of various directions in the same field, and inter-field connections reflect the infiltration and integration between different fields. Based on the intrinsic linkages between hotspots, triangular structures can be observed, such as the "Reduction of methane emission" hotspot in the agriculture field and two hotspots named "Analytic techniques of atmospheric CH_4 emission and sources" and "Remote sensing inversion technique and estimation of flux for greenhouse gases" in the fields of environmental and textile engineering , all of which are related to the study of greenhouse gas emissions. Another includes the "Flow, heat/mass transfer, and combustion under extreme conditions" hotspot in the field of energy and mining engineering, and the hotspots called "Preparation of porous surfaces and their applications in enhanced heat transfer" and "construction and application of superhydrophobic surfaces" in the fields of chemical, metallurgical, and materials engineering, which are all involved in basic research on heat transfer, mass transfer, momentum transfer, and chemical reactions.