

Safety Science Research: Global Research Trends and China's Recent Theoretical Progress

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Safety science is a relatively new research field because it didn't become an academic domain until the 1970s. In recent years, many scholars have carried out a great deal of safety science research. To understand the future development of safety science research, this article discusses the future trends in five safety science research directions (namely safety human factors, safety natural science, safety technology science, safety social science and safety system science) using mainly three methods, including typical literature search and review, speculation, and comparative analysis. Meanwhile, by reviewing some typical theoretical research achievements on safety science of the Safety & Security Theory Innovation and Promotion Center (STIPC) of Central South University (which is a representative research institution in the field of safety science theory in China) in recent years, this paper briefly introduces China's recent theoretical progress on safety science research from nine aspects (namely new disciplines of safety science, new safety theories, safety science methodology, safety science principles, theoretical safety models, comparative safety science, similarity safety systematology, safety culturology and safety informatics) respectively. The results show that the global research trends of safety science have undertaken a drastic shift, and safety science research has closely followed the demands of social and economic development. In a word, the theoretic foundation of safety science is gradually becoming mature and enrichment.

Keywords: safety science; research trends; theoretical progress

1. Introduction

As one of the basic needs of mankind, safety is the most indispensable guarantee for human production, life and development. Meanwhile, safety is a very promising industry at present and in the future. In order to promote safety, safety science research has received widely concerned in the academic domain in recent thirty years (Swuste et al., 2018). Safety science is a typical interdisciplinary discipline, and it is a scientific field with the rich connotation and the huge exploration space.

Although safety is an ancient and eternal topic, safety as a scientific issue to be investigated was up till the industrial revolution (Swuste et al., 2010; Swuste et al., 2014). In fact, it is hard to confirm exactly when safety science was taken as an academic discipline. Some scholars (such as Swuste et al., 2018; Hollagel et al., 2014; Stoop et al., 2015) pointed out that, the problem of safety had become a specialized field of scientific research from the middle of 1970s. Especially since 1980s, safety science had been developed rapidly, widely studied and paid attention to. After nearly half a century of development, safety science has basically formed its own research object, research area and research paradigm, and has gradually become an independent new discipline. Meanwhile, safety science has made a great contribution to the safe development and the progress of science and technology.

From the perspective of the world's industrialization development, the twentieth century can be regarded as a history of industrialization. During this period, safety science and the industry were accompanied by each other, and safety science was gradually changed with the development of industry. Therefore, in the twentieth century, the development of safety science had experienced two major changes in the machinery manufacturing (industry 1.0) era and the electrification and automation (industry 2.0) era. Specifically, for

Paper Received: 15 January 2019; Revised: 2 May 2019; Accepted: 28 June 2019

Please cite this article as: Wu C., Wang B., 2019, Safety science research: Global research trends, Chemical Engineering Transactions, 77, 1015-1020 DOI:10.3303/CET1977170

safety science, in the industry 1.0 era, its research object mainly is accidents caused by energy and substance, its research approach is mainly starting from the accident, its main purpose of safety science study is the prevention and control of accidents and injuries, and its representative achievements are the accident theories. In the industry 2.0 era, its research object is gradually turning to the safety and complex system safety, and its representative achievements are the birth and application of system safety engineering.

In recent twenty years, the world's population is expanding, the regional development is becoming more and more unbalanced, as well as the gap between the rich and the poor is growing. Meanwhile, the natural environment is deteriorating, the disasters occur frequently, the resources become more and more scarce, and the market competition becomes increasingly fierce. In addition, with the continuous innovation and development of science and technology, the artificial engineering has been gigantic, and information and network technologies have changed people's life styles. Also, systems are becoming more and more complex, and their interdependence is enhanced.

Obviously, the above a series of changes must cause the third historical development of safety science in the twenty-first century. Therefore, there are many changes in safety science happened, such as the connotation and extension of safety. New problems, new developments, and new fields of safety have come into being. Besides the safety problems brought by the first and second industrial transformations, the focus of safety science research will gradually turn to the new security issues related to the future and destiny of mankind, such as the prevention and control of anti-social behaviors, information security, life sciences and artificial intelligence (AI) security (Wang et al, 2018; China Occupational Safety & Health Association, 2008; Division of the Engineering and Materials of National Science Foundation of China, 2016).

Based on literatures (Wu, 2016; Wu, 2017; Wang et al. 2017; Wang and Wu, 2018), the purposes of this paper are to find out the future trends in safety science research to help safety researchers and practitioners understand the research trends and frontiers in the field of safety science

2. Research trends of safety human factors

The research trends of safety human factors mainly include:

(1) For accident prevention and control, the prevention and control of malicious (anti-social) terrorist activities have been becoming more and more important. For example, some typical events like the 'German wing A320 aircraft crash', the 'French Nice terrorist attack' and the 'US 911 terrorist attack' were caused by terrorist activities. Therefore, researches on terrorist attacks, and safety assessment concerning anti-terrorism are becoming increasingly crucial.

(2) The prevention and control of accidents resulting in injury and loss has turned to the promotion of occupational health and comfort. Therefore, researchers will pay more attention to the promotion of occupational health, health toxicology, life health and occupational comfort.

(3) On behavior-based safety management, its research turns to the more essential human factors, such as safety humanity, safety psychological process, and unsafe behavior intervention based on safety information. Therefore, safety humanity, safety psychology, safety cognition psychology, and unsafe behavior intervention will be developed further.

(4) On the transformation of behavior-based safety management modes, its research turns from universal safety management to personalized safety management. This change aims at making safety management more precise and humanized. Moreover, behavior-based safety management will be more humanized. For example, researchers will pay more attention to safety management based on safety humanity and the development of emotional safety culture.

(5) The research object of behavior-based safety management turns from individual behaviors related to safety to organizational behaviors related to safety, because the root cause of accidents caused by individual behaviors is the lack of organizational safety management system. The study on behavior-based safety management will be increasingly focused on the management of organizational behaviors related to safety.

(6) The injury prevention turns from physical injuries and occupational hazards to psychological trauma gradually. The assessment, intervention and rehabilitation of psychological trauma will be widely studied.

(7) The key points and responsibilities of the safety work will focus on enhancing the safe sense of individuals and collectives in the future. Therefore, the safe sense will become a new field of safety science.

3. Research trends of safety natural science

Safety natural science has the following research trends:

(1) There are some typical changes in the route, focus, content and scope of safety science research: (i) the route of safety science research turns from the accident-oriented to the safety; (ii) the focus of safety science research turns from the accident prevention and control to the safety promotion; (iii) the research on safety

science theory turns from the accident causation theory to the injury causation (safety promotion) theory; (iv) the system research method and the cross discipline research method are used widely in the safety science research; and (v) 6P features of safety science (namely foresight, preventive, personalized, participation, precision and public) are more distinctive.

(2) On the basic theory of safety science, the connotation of basic concepts (such as safety, risk, accident and injury) of safety science will be further enriched, and the logical relationship among these concepts will be clearer. Meanwhile, the basic theory of safety science will gradually become mature. In addition, the basic theory of safety science will be gradually used to more fields.

(3) In research methods of safety science, the research methodology of safety science has been widely studied and rapidly developed in recent years, and the combination of different research methods and the selection of targeted research methods are becoming increasingly important. Moreover, most of safety researchers like to use simple and intuitive research methods.

(4) In terms of the research on the causes of accidents, the theory or mechanism of accidents caused by hazards turns to the accidents caused by the lack of safety-related information.

4. Research trends of safety technology science

The research trends of safety technology science mainly include:

(1) In terms of safety risk prevention and control, the focus on direct safety risk shifts to both direct and indirect safety risks. Safety risk cognition, safety risk assessment and safety risk prediction are bound to be further studied.

(2) In terms of the accident prevention and control, the emphasis on explicit accidents turns to recessive accidents. In the future safety practice, the prevention and control of recessive accidents would have highly valued. Therefore, the traditional concepts of safety science, the definition of an accident, and the theory for the accident prevention and control, and accident investigation method are needed to update.

(3) In the research and development of specific safety technologies, the information technology, the AI technology, the big data technology and the cognitive technology will spawn a series of new safety technologies, and these technologies will significantly promote the safety management.

(4) The research on the technology safety turns from the safety of current technologies to the safety of future technologies. For example, although robots are of great help to mankind, there are more and more concerns about the safety of robots, like accidents or injuries caused by robots. Obviously, the safety of future technologies will be a leading issue in the future research of safety science.

5. Research trends of safety social science

There are eight research trends in safety social science, which are:

(1) In terms of the power for safety promotion, safety management approach turns from the passive constraint to active self-management. The safety identify, safety education and safety humanity will be continuously studied.

(2) On the research of safety issues, the focus on the "materials" safety problems turn to the safety problems caused by "event reasons". Safety management, safety culture, safety ethics and safety education need to be developed.

(3) On the research of safety elements, the emphasis on hard safety elements, the hard safety structure and hard safety forces turns to soft safety elements, the soft safety structure, and soft safety forces. Safety culture, safety ethics, safety management and other soft safety science will be more widely applied.

(4) In the aspect of safety promotion approach, safety management turns to safety governance. In the future, there will be a good situation for the whole people and the whole society to participate in the safety promotion. Therefore, the safety knowledge popularization work will get more and more attention.

(5) On the research of safety management methods, the application research based on the traditional safety management methods turns to the research on creating the new safety management methods. There is an urgent need to further think and explore new safety management basis and methods.

(6) On the selection of safety management basis, it is gradually turning from the emphasis on safety management experience (including the experience of safety experts), as well as safety laws and regulations to search for the best evidence. The practice of future safety management research will focus on finding and optimizing the best safety management plan based on the best evidence. In other words, evidence-based safety (EBS) management method will be widely researched and used.

6. Research trends of safety system science

Safety system science has the following research trends:

(1) The safety system science has been widely applied to the safety management of the relatively simple risk system and the complex giant system with the high risk. The research on the principle and method of the complex giant system safety management will be paid more attention and the relevant theories will be widely applied.

(2) The safety system science shifts from the focus of the safety entity of systems to the safety relations of system elements. Safety system thinking, safety association science, safety big data and so on will be more widely applied in system safety management. The branches of safety system engineering, safety relation science, and safety big data science will be developed rapidly.

(3) Safety system science has shifted from the investigation on the isolated safety events to the research on safety interconnections. Safety system engineering, safety relation science, safety information science and so on will be applied and developed.

(4) In order to simplify a complex safety problem and a uncertain safety problem to a deterministic safety problem, safety system science is turning to focus on the black box of complex safety problems. In order to solve the safety problems of complex systems effectively, modern applied mathematics, big data method and computer technology will be widely applied and developed in the field of safety system science.

(5) Emphasis on revealing and clarifying the safety reasons of events and on the statistical law of accident occurrence turns to the rules and applying theories of safety emergence, dissipation, mutagenicity and fuzziness. The corresponding branches (such as safety relation theory, safety traceability theory, big data analysis method applied to safety) will be developed rapidly and widely applied in the field of safety system science.

(6) The emphasis on safety engineering turns to focus on man-machine engineering. At present and in the future, the system design and operation will be considered by more the "people-oriented" concept will be widely used. The corresponding branches (such as safety human science, ergonomics, safety design and pleasant people science) will be further developed.

(7) The system reliability theory turns to the system resilience theory. System resilience theory will be gradually emerged and widely concerned in the field of safety system science. High reliability organization, system resilience theory and the new connotation of safety from the perspective of resilience will be investigated and applied. The theory of system resilience is bound to be the next research hotspot in the field of safety system science.

7. China's recent theoretical progress in safety science

The Safety & Security Theory Innovation and Promotion Center (STIPC) of Central South University is a representative research institution in the field of safety science theory in China. This paper briefly introduces China's recent theoretical progress on safety science research by reviewing some typical theoretical research achievements on safety science of the STIPC of Central South University. The research of the STIPC of Central South University mainly includes nine aspects (namely new disciplines of safety science, new safety theories, safety science methodology, safety science principles, theoretical safety models, similarity safety systematology, and safety culturology).

7.1 Progress in the new branch of safety science

To promote the development of safety science and construct the new branches of safety science, we have built more than thirty new branches of safety science, around the safety human science, safety natural science, safety technology science, safety social science, safety system science and safety cross sectional science in the past several years. More than thirty articles were published and a book titled "New Branches of Safety Science" (Wu and Wang, 2018) was also published. Several new disciplines, such as the science of safety science, comparative safety science, safety statistics, safety education science, safety similarity science and safety culturology have been built up and taken as the new courses of the program of safety science and engineering major at high education institutions.

7.2 Progress in the research of new safety theory

During the past several years, we invented and summarized some new safety doctrines (Ouyang and Wu, 2017; Yang and Wu, 2016; Wang and Wu, 2018a; Ouyang and Wu, 2018; Wang and Wu, 2016a; Ouyang and Wu, 2016; Wang and Wu, 2016b; Wang and Wu, 2018b), such as safety changes-reduction theory, safety dimensions-reduction theory, safety system of deductive logic, safety identify theory, safety big data theory, the theory of appreciation and evaluation of safety slogans, the mechanism and method of building safety concept and safety education, the theory of safety information behaviors, etc.

Because the safety science is mainly aimed at people, the contents are closer to social science. The safety development is very unbalanced, and it involves a wide range. Therefore, there is almost no uniqueness in the

theory of safety science, and new and more useful safety theories can be established from different spatiotemporal and visual angles.

7.3 Research progress on the methodology of safety science

The properties of safety discipline determine that it has the huge space and time. Therefore, safety science methodology is very important. Safety science methodology is a guideline for safety science research. Safety methodology research should be at the height of science of safety science, and should be based on the scientific methods of existing disciplines. Through the classification, induction, promotion and expansion, new methods applied to safety science can be created.

We have achieved some progresses in safety science methodology, such as the construction of safety science methodology system, the innovation of research methods on safety principles, the methods for building theoretical safety models, the theory of safety system research methodology, the EBS management method, as well as study methods of safety education, safety statistics and safety culture. Two books related to safety science methodology, namely "Safety Statistics" (Wu and Wang, 2012) and "Safety Science Methodology" (Wu, 2016) were published.

7.4 Progress in safety science principles

Every science has its own basic principles. Therefore, safety science should have own basic principles, too. The principles of safety science are very important, which are the theoretical pillar of safety science, the gene of the safety science innovation, the soul of the safety science development, the key to the accident prevention and control, and the guide for safety management.

At the macro level, we proposed and defined the structure system of the first-class safety science principles (Wu and Yang, 2012), which include the principle of safety life science, the principle of safety natural science, the principle of safety technology science, the principle of safety social science, and the principle of safety system science. Based on the five types of safety science principles, more than one hundred key sub-principles of safety science can be extracted from relevant disciplines. In recent years, we have published more than thirty papers about safety science principles (Wu, 2018). Also, more than ten research papers have been published to explain the principles of accident prevention, risk management and safety model. However, the safety science principles are still not enough, more safety science principles need to be summed up by researchers.

7.5 Research progress of theoretical safety models

A theoretical safety model can usually express the mechanism and operation pattern of a system. So far, there are hundreds of theoretical safety models. Unfortunately, due to the complexity and diversity of safety system problems, the existing theoretical safety models could not meet the need, as well as the evolution and development of social technology systems, complex systems and new safety problems emerge. Theoretical safety models need not only to be constantly updated, but also need to keep pace with the times, even ahead of the continuous research and construction of new theoretical safety models.

During the past several years, we achieved some progress in the theory and methodology of the theoretical safety models and created a series of new safety models, including system safety models, safety-related information cognitive models, safety big data models, behavior-based safety management models, safety management models, safety culture models, city's safety resource sharing models, and other dozens of new theoretical safety models, and published more than thirty papers (Wu, Huang and Wang, 2018).

7.6 Progress in the study of safety culturology

Safety culture has always been a hot topic in the field of safety science in recent years. We constructed a theoretical system of safety culturology, and published dozens of research papers related to safety culturology and a book named "Safety Culturology" (Wang 5 and Wu, 2017). This book covers the basic research, practical research and application research of safety culturology, and includes the following chapters: (i) the formation and development of safety culture, (ii) the origin and evolution of safety culture, (iii) the basic issues of safety culturology, (iv) the methodology of safety culturology, (v) the principles of safety culturology, (vi) the branches and extension of safety culturology, (vii) the practical application theory of safety culturology, and the (viii) typical examples of practical application of safety culturology.

In academic view, the shift from "safety culture" to "safety culturology" is not only a different word, but a qualitative leap. In a word, "safety culturology" should be the peak of safety culture, and its research and development are of great significance.

Acknowledgements

This study is supported by the Key Project of National Natural Science Foundation of China (No. 51534008).

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