

Domestic and international human reliability research field development tracking

Jia-tian Zheng^{1,a*}, Li-xia Niu^{1,b}

1013787122@qq.com^{a*}, nlx8941@126.com^b

¹School of Business Administration, Liaoning Technical University, Huludao Liaoning 125105, China

Abstract: In order to reveal the current situation and trends of human reliability (HR) research in China and abroad, we studied the current situation, research hotspots and development trends of HR in China and abroad using the bibliometric tool CiteSpace. The results show that: the disciplinary distribution of HR research in China and abroad shows interdisciplinary and multidisciplinary patterns, and the hot keywords of HR literature focus on human error tracing, reliability analysis, performance shaping factors, decision support, system safety, etc. According to the keyword clustering diagram, we can know the common research hotspots of human reliability analysis methods and complex system reliability in China and abroad. Relative to the research fields, in addition to the classical safety critical fields, foreign scholars are more enthusiastic in the research of medical and cognitive psychological fields. The keyword emergent graph indicates that the emergent words are fuzzy theory, human factors, uncertainty, dynamic probability simulation, etc. indicating that these research topics may become the future research frontier trends.

Keywords: human error; Bibliometrics; Hot content; Knowledge map

1 INTRODUCTION

Humans play an important role in socio-technical systems, participating in the design, construction, installation, maintenance and operation. With advances in materials, technology and engineering, the reliability of equipment in complex systems has steadily increased^[23], but it has also increased the complexity and risk of the system. From the point of view of system safety, human factors have become the main cause of system reliability in most accidents^[6]. Recognizing the importance of human factors in safety management, a large number of HR studies have been conducted in different safety areas, covering nuclear energy^[14], transportation^[20], oil sector^[12], healthcare^[11], etc. HR is described as the probability that someone will correctly complete the task required by the system within the specified time^[18]. The method used to assess human reliability can be defined as Human Reliability Analysis (HRA), which involves identifying, modeling and quantifying the probability of human error. It aims to systematically analyze the causes and consequences of human failures in various systems^[8].

In order to gain an understanding of the field of HR, many researchers have conducted corresponding literature reviews. Roughly distributed in terms of scope, methodology and potential models. Hamer R et al critically reviewed the last fifty years of research on human factors and ergonomics in nuclear safety^[9]. Salmon Paul M et al reviewed human error models as well as error management methods and dissected their application in the road transport

environment^[15]. Alvarenga et al. reviewed the means and models for assessing organizational factors in HRA^[1]. Although the above review studies provide valuable insights into the field of HR, a comprehensive quantitative analysis of the literature in the field is lacking. Compared to standard literature reviews, bibliometric analysis is an effective method for gaining high-level insight into the characteristics of a large body of academic literature within a given research area. Therefore, this paper intends to provide a systematic review of the HR literature based on a bibliometric analysis.

2 Data collection and research methodology

To ensure the accuracy and completeness of the data, academic journal papers on HR were collected from representative and authoritative databases in China and abroad. The data set of foreign research sample was obtained from Web of Science core collection database. The search formula "TS = ("human reliability*")", the document type "Article", and the language "English". The search was refined, and the results were checked and the low relevance documents were excluded. Finally, 922 valid foreign literature titles were obtained. The data set of domestic research samples was searched by CNKI with "human reliability" as the theme and "academic journals" as the literature type, and the search results were manually reviewed to remove invalid literature such as conferences, journal articles and popular science propaganda, and finally 325 valid Chinese literature titles were obtained. In addition, in order to ensure the comparability of the time dimension, the search time of both Chinese and foreign literature was set to 1987-2021, since the research on HR was conducted earlier in foreign countries and later in China.

This study takes innovation diffusion theory as the starting point, bibliometric citation analysis and co-occurrence analysis principles as the basis, and integrates traditional literature review methods and scientific knowledge mapping analysis methods to systematically sort out human factors reliability research in China and abroad, presenting the research paradigm and evolutionary path of a field in a comprehensive manner and scientifically guiding future research directions^[4], and this study uses the software CiteSpace for bibliometric analysis^[3]. The software is a visualization tool for detecting and visualizing the distribution characteristics of a field and has been widely used in many fields to identify new developments in the scientific literature regarding trends and dynamics. In the process of operation, in order to better describe and compare the basic profiles of related research fields in China and abroad, and to present the final analysis map in a visual way of "showing the whole network", the "pathfinding network algorithm" was used to simplify the relationship of measuring data similarity in the complex network of "human-caused reliability" knowledge map, so as to establish the most effective connection path between innovation diffusion hotspot data, and the specific parameter settings are shown in Table 1.

Table 1: Software operation parameters setting

Software Parameters	Setting
time slicing	From 1987 to 2021
node types	Keywords
selection criteria	Top 10%
pruning	pathfinder
visualization	show merged network

3 General characteristics analysis

3.1 Analysis of annual publications

The graph of annual publication changes in the literature can understand the output of HR research in China and abroad, and to a certain extent can reflect the academic attention of this research direction, understand its development and predict its development trend. As shown in Figure 1.

As shown in Fig. 1, the number of research articles issued by domestic scholars from 1987 to 2021 has shown an overall growth trend. The first peak of HR research in China was in 2012, when the National Energy Administration issued the *National Energy Science and Technology 12th Five-Year Plan*, and four fields such as nuclear energy and wind power were emphasized, which promoted HR research in nuclear energy and other safety fields. In 2015, when Li Keqiang delivered the Report on the *Work of the Government* at the National Congress, he proposed the grand plan of "Made in China 2025" for the first time, which further promoted the research on HR in China. However, the number of publications has not increased exponentially since then, which indicates that the domestic research on HR is still in the initial exploration stage.

In contrast, the number of HR studies abroad grew at a higher rate than in China from 1987 to 2021, mainly due to the fact that research on HR was conducted earlier and more conferences were held abroad. Among the conferences with high influence in the field of HR include *the International European Safety and Reliability Conference*, *the International Conference on Probabilistic Safety Assessment and Management*, and *International Conference on Reliability Systems Engineering*, all of which have been held for many years. To date, related research continues to be hot and increasing in depth.

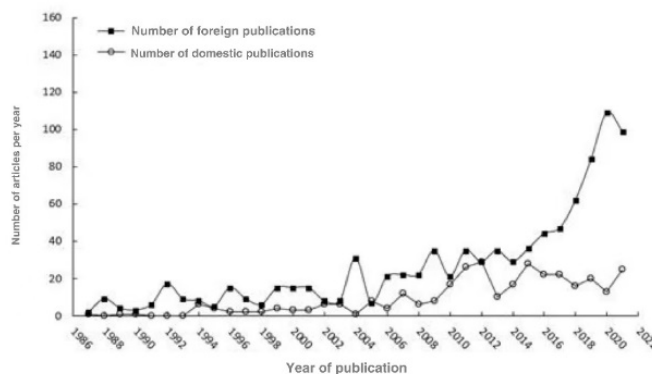


Figure 1: Annual paper output distribution of domestic and international HR research from 1987 to 2021

3.2 Statistical analysis of journals and disciplines

The statistical analysis of the distribution of journals is useful for scholars to understand the core journals in the field of data security research and their publication preferences, etc. and provides scholars with references for further research in the field. From the statistics of the

sample literature published in journals, the research in the field of data security has shown diversified development, among which the foreign language literature is distributed in 276 journals and the Chinese literature is distributed in 221 journals. The top 10 foreign journals with the most articles published a total of 439 articles, accounting for 47.61% of the total number of articles published, among which *RELIABILITY ENGINEERING SYSTEM SAFETY* has published the most articles with 209 articles, much higher than other journals, and is in the leading position in the field of data security research, followed by *SAFETY SCIENCE* and *ANNALS OF NUCLEAR ENERGY* in second and third place with 65 and 42 publications, respectively. The top 10 domestic journals published 198 articles, accounting for 42.46% of the total number of articles published; the journal with the most articles is the *Chinese Journal of Safety Science*, with 37 articles, followed by *Nuclear Power Engineering and Human Ergonomics*, which ranked second and third with 21 and 15 publications, respectively.

Analysis of the current state of development of disciplinary fields helps to understand the state of development of each discipline, identify research hotspots, and provide reference for predicting disciplinary development trends, thus guiding researchers in topic selection. The research in the field of HR is diversified and cross-cutting, and the research in foreign literature is mainly in the fields of industrial engineering and operation and management science, but also in the fields of nuclear science and technology, psychology, medicine, and multidisciplinary engineering. The research in Chinese literature is mainly in the fields of safety science and electric power industry, and also in the fields of nuclear science and technology, aerospace, and mathematics.

4 Identification of hot topics in domestic and international research

The keyword clustering function of CiteSpace software is used to extract noun terms from keywords by LLR algorithm to realize the naming of clusters, thus obtaining domestic and foreign cognitive computing research topic clusters, as shown in Figure 2 and Figure 3. From Fig. 2 and Fig. 3, we can see that fuzzy theory is a common research hotspot in the field of HR in China and abroad. Fuzzy theory mainly includes fuzzy set theory, fuzzy logic, fuzzy reasoning and fuzzy control, which can reflect the uncertainty phenomena in life and can reflect such phenomena through fuzzy functions.

Domestic research hotspots revolve around the following three areas:

(1) Scholars have studied HRA methods, mainly including clustering #0 human error tracing, #1 quantitative reliability analysis, and #6 data mining. The current domestic research on HRA mainly involves extending the basic HRA method or combining it with other quantitative methods. Considering the situational environment and human factors characteristics of aircraft piloting, Guo et al. adjusted the human error formation conditions in the original CREAM to make it more reasonable to characterize the pilot working situation in the cockpit^[21]. Zou et al. used the HCR model to introduce a fuzzy logic approach to model the uncertainty and fuzziness of human error formation conditions using an affiliation function to analyze the HR of offshore floating nuclear power plants^[17].

(2) Scholars have studied the system safety accident aspects, including clustering #2 safety evaluation, #3 human-caused accidents, and #5 safety engineering. With the emergence of complex human-machine systems, making more and more system safety accidents caused by human factors, system safety assessment and accident investigation focus from the initial

technical aspects of factors to human factors, and then more and more research began to include the consideration of organizational factors and other factors in the system safety analysis and assessment, that is, to carry out the system safety management research. Sheng et al. summarized the research on key technologies for dam risk assessment and management and looked at future research directions to promote the transformation of Chinese dams from "engineering safety management" to "risk management" as soon as possible^[16].

(3) Scholars have extensively focused on HR in major safety areas, mainly including clustering #4 control room, #8 information technology, and #9 deep sea operations. The first systematic assessment of HR was started in the military field to predict and quantify the probability of human error in nuclear weapons assembly, and the second originated from the development of probabilistic risk assessment in the nuclear power industry. The main research areas of domestic scholars are related to transportation field (aerospace, ships, etc.), oil field, construction field, information technology field, etc.

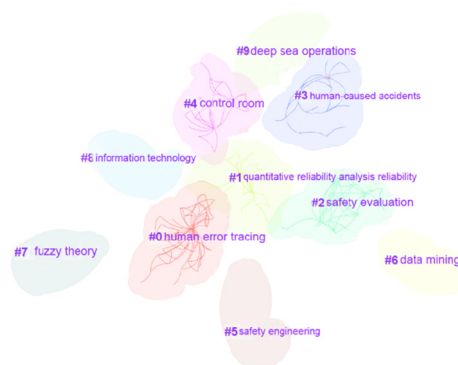


Figure 2: Keyword clustering map of HR in China

Foreign research hotspots revolve around the following four areas:

(1) Quantitative assessment of HR, mainly including clustering #0 human reliability assessment, #2 probabilistic risk assessment, #5 dependence assessment, #6 performance shaping factors. Initial research in HR first involved the quantification of risk assessment, combining human factors with established methods of risk and safety analysis, such as probabilistic risk analysis. At this stage, the research focus of foreign scholars is gathered on the dependency assessment in HR and the study of performance formation factors. Dependence assessment mainly addresses two issues: (1) how to assess the degree of dependency between manual tasks; (2) what is the impact of dependency on the probability of failure of the next manual task. Typically, the greater the correlation between two consecutive tasks, the higher the probability of failure of the next task when the current one fails^[7]. Adequate assessment of inter-task dependencies is a necessary prerequisite for obtaining reasonable risk analysis results^[24]. Additional scholarly research involves collecting empirical data to assess the quantitative relationship between performance shaping factors (PSFs) and the probability of human-caused failure.

(2) The study of the reliability of complex systems. It mainly includes clustering #1 complex system accident. The main challenge in system reliability assessment is to efficiently and accurately determine the probability of joint safety events. Byeng D. Youn addressed this problem by proposing complementary intersection (CI) events, enabling the development of

complementary intersection methods (CIM) for system reliability analysis^[22]. Since some methods are difficult to obtain models directly from the specification and cannot model the reliability interactions between components or subsystems, methods such as dynamic fault trees and dynamic reliability block diagrams have been developed subsequently^[5]. Additional methods with high occurrence are Monte Carlo simulation algorithms (MCS), and Robert li created a hybrid algorithm using MCS and SVM to replace the linear programming typically used for classification during power system reliability assessment^[10].

(3) Research in the medical field. It mainly includes clustering #4 surgery. In addition to foreign scholars' research on HR in major security fields like domestic scholars, it is worth mentioning that the number of HR studies in the medical field is much higher than that of domestic scholars. From the earliest applications of qualitative methods (questionnaires, interviews, etc.) to study adverse events in health care. In the middle stage, the HR method was used to evaluate the surgical performance, and Tang et al. further proposed a combined method, which combined OCHRA with objective structured clinical examination (OSCE) to evaluate the ability during laparoscopic surgery^[19]. The latest proposed approach to the integration of surgical robots into the surgical environment, Ken R et al. study surgical blood flow disruption associated with the da Vinci robotic surgical system and relate it to the surgical environment and trainee skill development^[2].

(4) Research in human cognition. It mainly includes clustering #3 cognitive, #7 information security, #8 human performance assessment, and the main keywords are operator response, cognitive model, fatigue, organizational factors, and decision support. Cognition plays a prominent role in the human decision making process. In addition to research on human behavior and motivation in the psychological, behavioral, and management sciences, the field of HR has studied the interaction behavior between humans and their external environment. Foreign scholars have mainly experienced the earliest proposed models of cognitive mechanisms in human error, such as the classical SRK model that divides human behavior into three levels: skill-based, rule-based and knowledge-based, each corresponding to different human error mechanisms and failure models; to studies involving human thought processes affecting human behavior in human-environment interaction, such as how to diagnose or control systems in working conditions; to recent studies of cognitive models based on artificial intelligence techniques in the computer domain, which focus on revealing how human cognition is achieved in the thinking process and on particular human cognitive mechanisms and cognitive behaviors that occur in the real world (e.g., human memory and language comprehension).

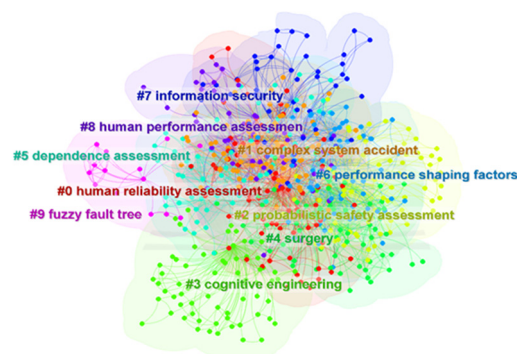


Figure 3 :Foreign HR keyword clustering mapping

The comparative analysis between domestic and foreign research hotspots reveals that there is a certain gap between domestic and foreign research on HR at present. On the one hand, in terms of HR analysis methods, most domestic scholars expand and apply on the basis of HR models researched by foreign scholars or combine with other quantitative methods to build an assessment index system suitable for the domestic environment. At present, foreign scholars mainly focus on the quantitative assessment of HR, involving the assessment of dependency between tasks and the study of human factors failure probability. On the other hand that is, the difference in the key research areas in China and abroad, in addition to safety critical areas (nuclear power and aerospace, etc.) have received research attention, foreign scholars are more enthusiastic about medical and cognitive-psychological fields, domestic scholars that is, the research on carrying out system safety management as a research hotspot.

5 Frontier analysis of HR research

The research frontier is the latest and most promising professional field in a certain scientific research, usually manifested as a set of emergent dynamic concepts, and the keyword surge index can detect the keywords with high frequency change rate at a certain stage, which represent the frontier and trend of a certain scientific research to a certain extent. Using CiteSpace to detect keywords in data security research sample literature, the top 15 keywords in terms of occurrence rate are finally obtained, as shown in Figure 4, and the future research directions are prospected based on the burst graph

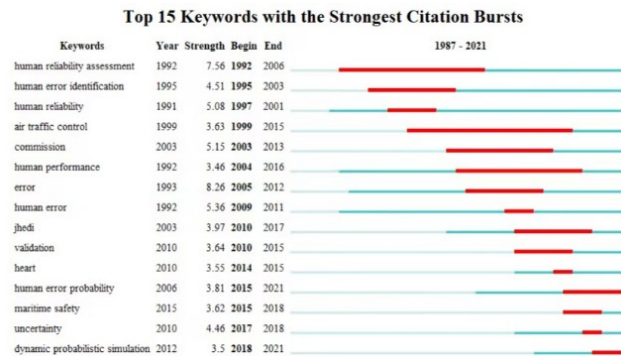


Figure 4 :HR Top 15 burst Keywords

5.1 Development of appropriate human factors experimental methods to suit the digital era

It has been suggested that more HR studies emphasize human factors analysis rather than human factors experiments^[13]. Therefore it is crucial to develop appropriate human factors experiments for future research. With the rapid development of computer science, computer simulations can provide more accurate and detailed scenario evolution and contextual information for HR studies, and artificial intelligence and software simulation tools should be widely introduced in the field of HR to predict human errors based on cognitive models. And so would the challenge of capturing the specific elements of the design that support or hinder the operator's work in an appropriate manner to enable a realistic and consistent human error probability (HEP) assessment and comparison of alternative solutions.

5.2 Reducing uncertainty in expert judgment

Many tasks in HR (e.g., assigning values to PSFs and evaluating HEPs) rely heavily on expert judgment to generate reliability data. In many cases, expert opinions are often vague, uncertain, or even incomplete due to time pressures, lack of knowledge, and limited expertise related to the problem area. Therefore, it is promising to use various uncertainty theories, such as Pythagorean fuzzy sets, probabilistic linguistic term sets, and cloud model theory, to effectively deal with uncertainty in expert judgment and to propose a traceable and defensible method to characterize the experience and knowledge of experts.

5.3 Application of emerging technologies in the field of HR

Another possible direction for future work is the use of techniques such as artificial intelligence tools to address HR assessment issues. For example, deep learning algorithms can be used to learn the degree of dependence of human failure events from expert assessment data for each pair of subsequent tasks. Neural networks can augment estimation methods for HEPs to account for fluctuations in human error assessments in the way the human brain changes. Moreover, the development of computer-aided tools for performing HRA calculations given in the literature is certainly an important direction for practitioners to effectively manage large and complex systems.

References:

- [1] Alvarenga, M. and P. Melo, et al. (2014). "A critical review of methods and models for evaluating organizational factors in Human Reliability Analysis." *Progress in Nuclear Energy* 75 (75): 25–41.
- [2] Catchpole and R. Ken, et al. (2018). "Diagnosing barriers to safety and efficiency in robotic surgery." *Ergonomics: The official publication of the Ergonomics Research Society*.
- [3] Chen, C. (2006). "CiteSpace II : Detecting and Visualizing Emerging Trends." *Journal of the American Society for Information Science & Technology* 57 (3): 359-377.
- [4] Chen, C. (2017). "Science Mapping: A Systematic Review of the Literature." *Journal of Data and Information Science* 2 (2): 1-40.
- [5] DistefanoSalvatore and PuliafitoAntonio (2009). "Dependability Evaluation with Dynamic Reliability Block Diagrams and Dynamic Fault Trees." *IEEE Transactions on Dependable and Secure Computing*.
- [6] Dougherty, E. (1993). "Context and human reliability analysis." *Reliability Engineering & System Safety* 41 (1): 25-47.
- [7] Gao, X. and X. Su, et al. (2021). "Dependence assessment in human reliability analysis under uncertain and dynamic situations."
- [8] Griffith, C. D. and S. Mahadevan (2011). "Inclusion of fatigue effects in human reliability analysis." *Reliability Engineering & System Safety* 96 (11): 1437-1447.
- [9] Hamer, R. and P. Waterson, et al. (2020). "Human Factors and Nuclear Safety Since 1970 - A Critical Review of the Past, Present and Future." *Safety Science* 133: 105021.
- [10] Ii, R. C. G. and L. Wang, et al. (2011). Composite power system reliability evaluation using support vector machines on a multicore platform. *International Joint Conference on Neural Networks*.
- [11] Liu, H. C. and Z. Li, et al. (2018). "A large group decision making approach for dependence assessment in human reliability analysis." *Reliability Engineering & System Safety*:

S095183201730916X.

- [12] Mara, B. and C. Eld, et al. (2019). "A human reliability analysis methodology for oil refineries and petrochemical plants operation: Phoenix-PRO qualitative framework." *Reliability Engineering & System Safety* 193.
- [13] Pan, X. and Y. Lin, et al. (2017). "A Review of Cognitive Models in Human Reliability Analysis." *Quality & Reliability Engineering International* 33 (7): 1299-1316.
- [14] Romina D. Calvo Olivaresa, B. and S. R. Selva, et al. (2018). "A novel qualitative prospective methodology to assess human error during accident sequences." *Safety Science*.
- [15] Salmon, P. M. and M. G. Lenné, et al. (2010). "Managing error on the open road: The contribution of human error models and methods." *Safety Science* 48 (10): 1225-1235.
- [16] Sheng J B, L. D. D. C. (2018). "Research progress and its practice of key techniques for dam risk assessment and management (in Chinese)." *Sci Sin Tech* 48 (10): 1057-1067.
- [17] Shufan, Z. S. H. B. (2020). "Human cognitive reliability model of marine floating nuclear power plants." *China Safety Science Journal* 30 (01): 1-6.
- [18] Swain, A. D. (1990). "Human reliability analysis: Need, status, trends and limitations." *Reliability Engineering & System Safety* 29 (3): 301-313.
- [19] Tang, B. and A. Cuschieri (2020). "Objective assessment of surgical operative performance by observational clinical human reliability analysis (OCHRA): a systematic review." *Surgical Endoscopy* 34 (9666).
- [20] Wang, N. and X. Du, et al. (2020). "An improved weighted fuzzy CREAM model for quantifying human reliability in subway construction: Modeling, validation, and application." *Human Factors and Ergonomics in Manufacturing & Service Industries* 30 (4).
- [21] Youchao, G. Y. S. (2021). "Human reliability assessment model for aircraft operating based on FBC REAM method." *Science Technology and Engineering* 21 (27): 11843-11849.
- [22] Youn, B. D. and P. Wang, et al. (2007). Complementary Interaction Method (CIM) for System Reliability Analysis. 48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference.
- [23] Zhan, Y. and P. R. Tadikamalla, et al. (2019). "Human reliability study on the door operation from the view of Deep Machine Learning." *Future Generation Computer Systems* 99: 143-153.
- [24] Zio, E. and P. Baraldi, et al. (2009). "A fuzzy set-based approach for modeling dependence among human errors." *Fuzzy Sets & Systems* 160 (13): 1947-1964.