REVIEW ARTICLE

Scientometric Analysis of Human Error Research and Human Reliability in Industries (1980-2022)

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Abstract

Background: Accidents caused by human error often lead to severe incidents. Correctly understanding human errors is essential to prevent such occurrences. Therefore, the purpose of the present study was to conduct a scientometric analysis of human error research in various industries.

Methods: This study was conducted using scientometric methods. It includes all articles published and indexed in the Web of Science (WoS) database. The study is a review that aims to synthesize and analyze the existing literature. In total, 845 articles were included in this study. VOSviewer and Bibliometrix, an R package, were used to perform the scientometric analysis of these articles.

Results: Industrial human error research is generally related to marine safety and accidents, the aviation industry, nuclear power plants, oil and petrochemical industries, occupational accident analysis, occupational fatigue, ergonomic issues, safety analysis of process systems, and the construction industry. Concepts such as "Human error," "Human reliability analysis," and "Human reliability" (with frequencies of 196, 113, and 64, respectively) were identified as the most frequently used keywords in the field of human error research.

Conclusion: The co-occurrence map of keywords in human error reveals that most studies focus on diagnosis and assessment rather than preventing human errors. Only a tiny percentage of studies address the prevention of human errors. Therefore, greater attention needs to be paid to prevention and protective measures.

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Introduction

In today's developed world, accidents are among the most significant problems. Statistics show that more than 90% of industrial accidents are directly or indirectly related to human errors.[1] Any deviation in human performance from specified rules and duties is considered a human error, which adversely affects system efficiency.[2] The analysis of catastrophic events, such as the fatal accident in Bhopal, India, and the Chernobyl disaster, has demonstrated that human error played a significant role in these incidents.[3] Research on industrial accidents indicates that human error is responsible for more than 90% of accidents in nuclear industries, 80% in processing industries, 75% in marine accidents, and 70% in aviation accidents.[4] Job-related tasks often lead to unsafe behaviors and actions, which result in unfortunate consequences.[5] The significance of human error in accident occurrence is evident, and the disastrous outcomes of not considering human errors in risk calculations have been well-documented.[6]

Studies have shown that human error occurs as a result of a combination of various factors, including personal attributes, managerial and organizational aspects, the complexity of work methods, environmental conditions, equipment and device design, training methods, supervision, and the availability of work instructions.[7] Therefore, multiple factors contribute to human errors and their consequences. Despite evidence of the role of human errors in accidents and the catastrophic outcomes resulting from their neglect in risk calculations, human errors are often not considered when evaluating safety parameters in industries.[8]

Many research articles, primarily review studies, have been published on the importance of human error and its role in occupational accidents. These studies often focus on specific topics or units of knowledge. However, review studies do not clearly illustrate the network, structure, interactions, crossovers, evolution, and other implicit relationships between knowledge units. These complex relationships generate new knowledge, serving as a critical guide for identifying hot topics and research frontiers in the scientific domain.[9]

In the science production cycle, recent research builds upon previous studies. Today, the volume of scientific studies has grown significantly due to advancements in information and communication technologies, the expansion of universities and research centers, an increase in the number of researchers, and the promotion of scientific collaboration. Consequently, researchers often cannot review all the papers published within a specific subfield. Therefore, it is essential to identify the most influential scientific studies, researchers, universities, scientific centers, and countries active in various areas and introduce them to the broader scientific community.

Scientometrics, as a branch of information science, facilitates the identification of these key elements and cores within scientific networks.[10] It is a quantitative method used to evaluate and compare the scientific publications of universities, research institutions, specific subjects, and authors. The findings from scientometric studies serve as crucial policy tools for advancing science, technology, and innovation in different countries worldwide. Additionally, the international significance of scientometric studies enables comparisons and fosters scientific competition on a global scale. Ultimately, the scientific outputs of countries can be aligned with global standards for science production.[11]

Scientometric methods provide a practical approach for gaining high-level insights into a research area. These methods also facilitate identifying and interpreting patterns, developments, and trends with ease.[12] The primary purpose of this article is to analyze the number of publications, identify the most influential authors, institutions, and countries, and examine their collaborative relationships. Additionally, it aims to highlight the most impactful journals, articles, and authors based on citations and co-citations and uncover hot research topics and emerging trends in the field of human error research related to the industry.

Methods

This research is applied in nature and was conducted using scientometric methods. The statistical population comprised all human error-related articles published in the Web of Science (WoS) database from 1980 to 2022. Commonly used databases for research include WoS, Google Scholar, Scopus, and PubMed. Among these, WoS is a central, large-scale database that covers various scientific fields and includes many of the most prestigious academic journals.[13]

This study utilized the WoS database to analyze human error research's current state and development trends. Data were collected from the WoS Core Collection database. The keywords Human Error and Human Reliability were used in the advanced search section in the initial stage. Subsequently, all scientific outputs were retrieved using the following search formula: (((TI=("Human error")) OR TI=(Human AND Error)) OR TI=("Human Reliability")) OR TI=(Human AND Reliability)).

Three thousand eight hundred eighty-two records were obtained from the WoS database search, limited to articles and review articles. Another limitation of this study was the inclusion of articles published only in English. Ultimately, 2,056 records were retrieved as of 5 August 2022. To ensure validity and reliability, the researchers reviewed the retrieved articles' titles and abstracts at the data collection's conclusion. Articles related to human error in industries were screened and matched with the study's objectives. Finally, after excluding articles from the fields of medicine and healthcare, 845 articles were included in the analysis.

The free and publicly available VOSviewer tool was used to create bibliographic networks, employing a similarity visualization approach.[14] This tool is widely utilized for mapping cluster networks of authors, journals, collaborating countries, and co-citations within the broader scientific and safety literature. VOSviewer also incorporates text-mining algorithms to identify noun phrases from the titles and abstracts of publications. These algorithms are used to generate networks, clusters, and heat maps.[15]

Additionally, the *Bibliometrix* package in R software was used in this study to enhance the analysis of results. This software offers greater control over modifying and adjusting input and output data compared to other bibliometric tools, such as BibExcel and Gephi.[16] *Bibliometrix*, a unique open-source tool developed by its authors, was utilized to analyze comprehensive scientific maps. It supports a recommended workflow for conducting bibliometric analyses. The tool is highly flexible, easily upgradeable, and integrable with other R statistical packages. Consequently, it is particularly valuable in the dynamic and ever-evolving field of bibliometrics.[16]

Results and Discussion

A literature search was conducted in the WoS database using the key terms *Human Error* and *Human Reliability* in the article titles. The search results included journal articles, conference papers, books, book chapters, etc. However, only original and review articles were included in this study. The search was performed on 5 August 2022, resulting in 3,882 records. These records were then filtered to include only original and review articles, reducing the number to 2,126. Furthermore, the number of articles decreased to 2,056 after limiting the language of the articles to English.

The main inclusion criteria for this study were original and review articles, articles in English, those related to human error in industry, and the exclusion of articles in medicine and healthcare. Following data collection, the researchers reviewed the titles and abstracts of the retrieved articles to ensure validity and reliability. Eight hundred forty-five original and review articles on human error in industries were selected. The earliest articles (6) in this area were published in 1980. Additional details are provided in Table 1.

Table 1: Descriptive Overview of Scientific Articles Retrieved from the WoS Citation Database (August 2022)

Period	1980-2022
Total number of articles extracted	845
Sources (Journals, Books, etc.)	296
Keywords Plus (ID)	639
Author's Keywords (DE)	1226
Average years from publication	12.1
Average citations per document	18.41
Average citations per year per doc	1.952
Authors	1872
Article	814
Review	31
Documents per Author	1.37
Authors per Document	0.73

Publication Trends in Human Error

A detailed analysis of the content of the selected articles was conducted to understand the evolution, themes, and trends in human error research. Figure 1 illustrates the annual publication process of articles.

The publication trend, reflecting the number of papers published, is a quantitative indicator of scientific activity and the growing attention to a particular field.[12] The first article on human error related to industries was published in 1980. This article, authored by Ricketson et al., analyzed aviation accidents and was published in *Aviation, Space, and Environmental Medicine*. Berkovitch (1980) also studied reducing human errors in control rooms. Danaher (1980) also published an article on human error in air traffic control (ATC) system operations in the *Human Factors* journal.

The results show that from 1980 to 1990, the average scientific production increased from 2.8 articles per year (82 articles) to 1.33 articles per year (331 articles) from 2010 to 2019. This growth highlights the increasing trend in scientific production, the rising importance of human error in occupational accidents, and its application in the industrial sector. The number of published articles rose steadily from 2016 to 2021, accounting for nearly half of those published from 1980 to 2022.

Since 2007, human error in industries has become a primary focus of researchers, leading to a significant increase in the output of scientific research. Generally, research in the area of industrial human error is linked to marine-related activities (facilities, safety, and accidents), the aviation industry, nuclear power plants,

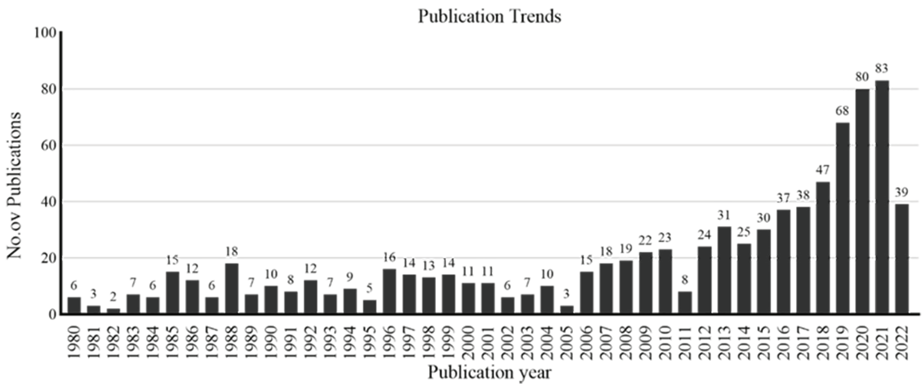

Figure 1: Annual Trend of Article Publications on Industry-Related Human Error

Table 2: Leading Authors in the Field of Human Error (Source: Author Analysis of WoS Data)

Authors	Articles	The year with the most published articles (Number of articles)	Publication period of articles
Dhillon BS	23	1985 (5)	1982-2007
Akyuz E	11	2016 (4)	2014-2022
Kirwan B	11	1997 (5)	1987-2008
Kim J	8	1 article/year	2003-2022
Islam R	7	2017 (2)	2016-2020
Park J	7	2022 (3)	2018-2022
Jang I	5	2016 (2)	2013-2021
Kim Y	5	2017 (2)	2015-2022
Stanton NA	5	1 article/year	1998-2017
Tavakoli M	5	2022 (3)	2020-2021

the oil and petrochemical industry, occupational accidents and accident analysis, occupational fatigue, ergonomic issues, system safety, and the construction industry. The most commonly used human error methods include the CREAM, HEART, and THERP.

Most Productive Authors

Identifying the most active authors in a field can significantly contribute to the growth and evolution of a research area. Knowing these scientists also aids in determining who can be approached for research collaboration, policy formulation, and assistance with organizational issues in a particular domain.[17] Table 2 lists the top authors in human error. Dhillon BS has the highest number of publications. Akyuz E and Kirwan B follow closely, holding the second and third positions, respectively. Three top researchers are affiliated with universities in South Korea, with other leading contributors from Canada, Turkey, France, and Australia.

Leading Authors, Institutions, and Countries/Regions

Leading Authors and Collaborations

Authors are key knowledge producers, and analyzing their contributions can reveal outstanding researchers and their social relevance. The complete scientific collaboration network is shown in Figure 2, listing prominent authors in the area of human error. The red cluster, comprising 13 authors, represents the most extensive collaboration network, followed by the green and blue clusters. The size of each node is proportional to the number of publications by the author, while the node's color indicates the clusters of authors within the same group. Additionally, the links between authors represent their collaboration relationships, with the strength of the link reflecting the extent of collaboration between authors.[18]

Leading Countries/Regions and Collaboration

The collaboration relationships among countries/regions in the explored field were visualized and analyzed using cooperation network analysis to examine countries and related institutions through VOSviewer software. As shown in Figure 3, the minimum number of articles was set to 5, and 28 countries/regions out of 59 were included in the network.

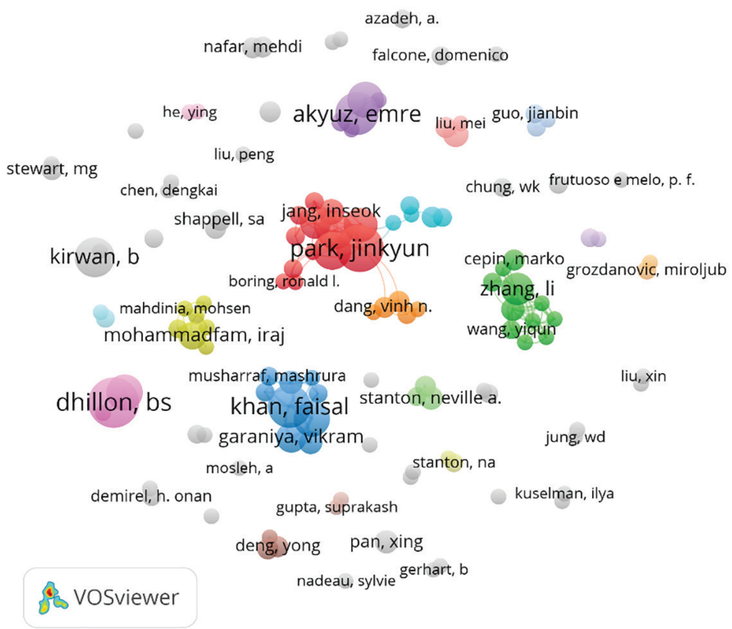

Figure 2: Author Collaboration Network in Human Error Research (1980-2022, Minimum Publications=2)

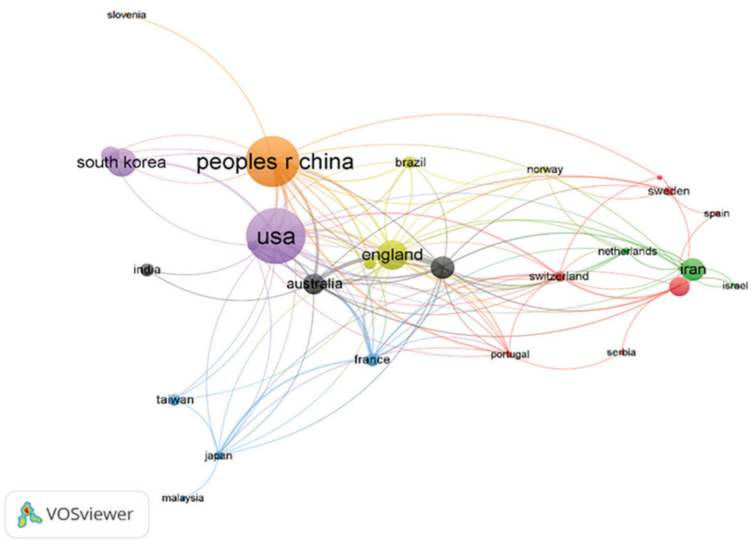

Figure 3: Inter-Country/Region Collaboration Network in Human Error Articles

Each node represents an author of a publication within the network.[19] The node's color indicates each country's average publication time, while its size reflects the number of publications. The thickness of the links represents the degree of international cooperation. Larger nodes signify more influential countries/regions; the thicker the link, the closer the collaboration between countries/regions.[20]

According to the results shown in Figure 3, the USA (with 137 articles and 3,994 total citations) and the People's Republic of China (with 123 articles and 1,286 total citations) play a dominant role in this area. The USA has the most collaboration and research relations, primarily with the People's Republic of China, followed by South Korea. Additionally, the total number of citations for the top three countries was as follows: the USA (3,994 total citations), England (1,832 total citations), and the People's Republic of China (1,286 total citations). The countries with the highest number of links to other countries included England (55 total link strength), the People's Republic of China (52), Australia, and the USA (45). In recent years, the People's Republic of China, Iran, and Turkey have been the most active countries in this field (Table 3). Overall, strengthening international cooperation is essential for sharing knowledge globally.

Figure 4 illustrates the collaboration network of institutions in the area of human error from 1980 to 2022. The size of each node represents the number of publications (the larger the node, the more publications). The links between the nodes indicate the strength of cooperation (the thicker the link, the closer the collaboration). The institution with the highest number of articles (33) is the Korea Atomic Energy Research Institute (South Korea).

Table 3: Total Number of Articles Published by the Top 20 Countries (Minimum of 10 Articles) from 1980 to 2022

Country	Documents	Citations	The total strength of the bond
USA	137	3994	45
Peoples r China	123	1286	52
England	62	1832	55
South Korea	60	851	10
Canada	45	1092	42
Iran	44	264	9
Australia	40	672	45
Italy	37	751	18
turkey	33	755	4
India	23	262	2
France	22	567	27
Brazil	21	450	14
Germany	20	250	25
Taiwan	20	354	4
Switzerland	17	664	21
Scotland	16	196	31
Sweden	15	346	12
Japan	14	137	15
Netherlands	11	117	13
Norway	10	150	7

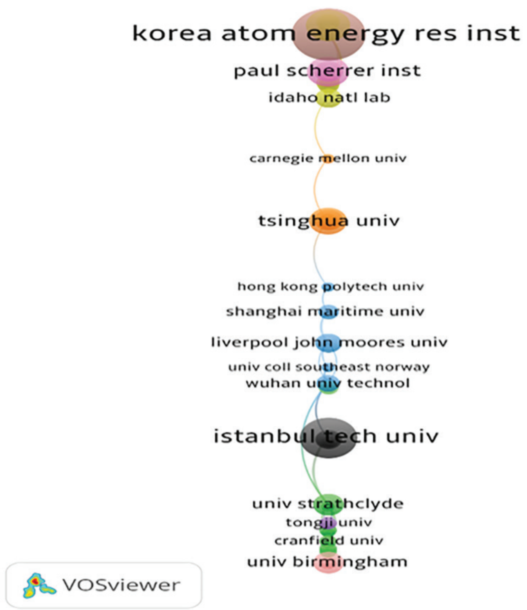

Figure 4: Collaboration Network of Countries/Regions in Human Error Articles

Istanbul Tech University (Turkey) and Memorial University of Newfoundland (Canada) rank second and third, respectively. Memorial University of Newfoundland (Canada) has the highest total number of citations (693), followed by Cornell University and Vanderbilt University (USA). Memorial University of Newfoundland, the University of Tasmania, and the Korea Atomic Energy Research Institute have the most links and international cooperation (Table 4).

Reliability Engineering & System Safety, Safety Science, and Microelectronics and Reliability were the leading journals in this field. Understanding which journals publish human error research helps researchers follow specific journals and also publish their studies related to human error in these journals.

Bradford's law is often used to select scientific journals for libraries, evaluate journal coverage by databases, and more. It is also employed in determining core journals, evaluating collections, conducting cost-benefit analyses, and selecting high-priority journals. According to Bradford, the validity of a journal depends on the number of references it receives and the number of articles published in it[21]. The present study applied Bradford's law to identify core journals (Table 5).

Influential Works

Influential Works Published by Human Error

Highly cited publications indicate the impact of a work within a specific research area. For instance, the number of publications exceeding a certain citation threshold allows for the identification of works with a significant level of impact.[18]

Analyzing the most productive authors provides essential information about individual contributions and their influence on the evolution of a research field. Equally important is identifying the most influential or cited research articles that have helped shape the knowledge structure of a field. Table 6 lists the top research articles in terms of citations in the area of human error.[20]

This section introduces articles with more than 100 citations as influential works in human error. The top 20 articles in terms of citations are listed in Table 6. The article by Gerhart B (2000) had the highest number of citations, with 351 citations. Additionally, four articles had a total of more than 200 citations (Figure 5). A few publications account for many self-citations, suggesting that review articles are more likely to receive more citations.

The co-citation network was created using highly cited sources with at least 20 citations per article. Sixty-seven highly-cited references were identified, and 1,988 human error references were obtained. The co-citation network derived from these 67 articles is shown in Figure 6. Labels display only the first author or the first two authors and the year of publication. Additionally, inter-node links represent the co-citation relationships between these highly-cited sources. The extent of the links indicates the strength of common citations between these references. Various groups of these sources are shown in different colors.

Table 4: Top Ten Institutions in the Field of Human Error by Publication Volume

Organization	Country	Documents	Citations	The total strength of the bond
Korea Atomic Energy Research Institute	South Korea	33	482	13
Istanbul Technical University	Turkey	22	553	11
Memorial University of Newfoundland	Canada	20	693	17
Beihang University	China	17	121	5
Korea Advanced Institute of Science & Technology	South Korea	14	274	12
Paul Scherrer Institute	Switzerland	13	543	4
University of Tasmania	Australia	13	302	15
Hamadan University of Medical Sciences	Iran	12	46	3
Hunan institute of technology	China	11	40	10
Tsinghua university	China	11	103	6

Table 5: Key Journals and Bradford's Law Review in Human Error Research

SO	Rank	Freq	CumFreq	Zone
Reliability engineering & system safety	1	114	114	Zone 1
Safety science	2	52	166	Zone 1
Microelectronics and reliability	3	33	199	Zone 1
Annals of nuclear energy	4	22	221	Zone 1
Quality and reliability engineering international	5	18	239	Zone 1
International journal of industrial ergonomics	6	16	255	Zone 1
Applied ergonomics	7	15	270	Zone 1
Journal of loss prevention in the process industries	8	15	285	Zone 1
Nuclear engineering and technology	9	15	300	Zone 2
Process safety progress	10	14	314	Zone 2

Table 6: Top-Cited Article in Industry-Related Human Error Studies

Authors	Title	Source	Total citations
Gerhart B, 2000	Measurement error in research on human resources and firm performance: how much error is there, and how does it influence effect size estimates?	Personnel psychology	351
Rasmussen J, 1982	Human errors. A taxonomy for describing human malfunction in industrial installations	Journal of Occupational Accidents	312
Wiegmann DA, 2001	Applying the human factors analysis and classification system (hfacs) to the study of commercial aviation accident data	Aviation, Space, and Environmental Medicine	212
Harati-Mokhtari A, 2007	Automatic Identification System (AIS): Data Reliability and Human Error Implications	The Journal of Navigation	201
Shappell S, 2007	Human Error and Commercial Aviation Accidents: An Analysis Using the Human Factors Analysis and Classification System	The Journal of the Human Factors and Ergonomics Society	200
Celik M, 2009	Analytical HFACS for investigating human errors in shipping accidents	Accident Analysis & Prevention	179
Stanton NA, 2009	Human error taxonomies applied to driving: A generic driver error taxonomy and its implications for intelligent transport systems.	Safety Science	168
Dekker SWA, 2002	Reconstructing human contributions to accidents: the new view on error and performance	Journal of Safety Research	166
Reinach S, 2006	Application of a human error framework to conduct train accident/incident investigations	Accident Analysis & Prevention	166
Wright PM, 2001	Measurement error in research on human resources and firm performance: additional data and suggestions for future research	Personnel psychology.	157
Shorrock ST, 2002	Development and application of a human error identification tool for air traffic control	Applied Ergonomics	155
Norman DA, 1983	Design rules based on analyses of human error	Communications of the ACM	154
Onisawa T, 1988	An approach to human reliability in man-machine systems using error possibility	Fuzzy Sets and Systems	152
Konstandinidou M, 2006	A fuzzy modeling application of CREAM methodology for human reliability analysis	Reliability Engineering & System Safety	149
Kirwan B, 1996	The validation of three human reliability quantification techniques — THERP, HEART, and JHEDI: Part 1 — technique descriptions and validation issues	Applied Ergonomics	138
Gerhart B, 2000	Measurement error in research on the human resources and firm performance relationship: further evidence and analysis	Personnel psychology.	125
Mkrtchyan L, 2015	Bayesian belief networks for human reliability analysis: A review of applications and gaps	Reliability Engineering & System Safety	115
Martins MR, 2013	Application of Bayesian Belief networks to the human reliability analysis of an oil tanker operation focusing on collision accidents	Reliability Engineering & System Safety	113
Dhillon BS, 2006	Human error in maintenance: a review	Journal of Quality in Maintenance Engineering	113
Swain AD, 1990	Human reliability analysis: Need, status, trends, and limitations	Reliability Engineering & System Safety	113

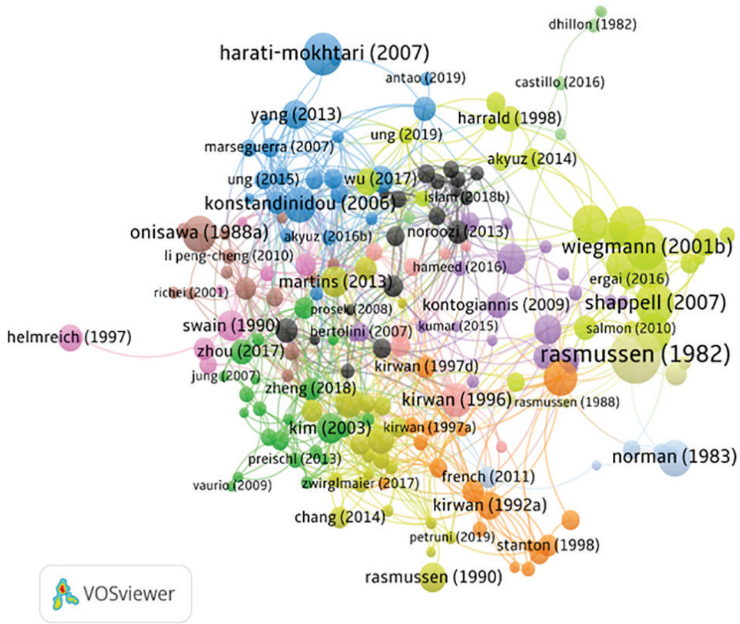

Figure 5: Distribution of Articles by Citation Count (20+ Citations)

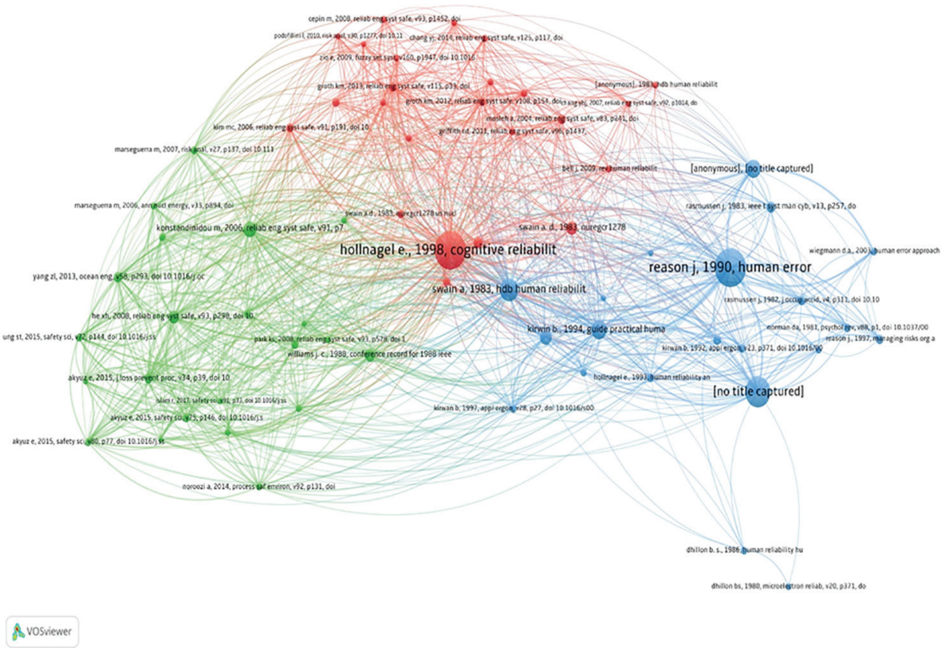

Figure 6: Co-Citation Network of Highly-Cited Groups Based on Typical Citation Power

The co-citations of these sources were clustered based on strength using VOSviewer software for bibliometric data analysis. Checked references can only belong to one cluster. Their position in the overall network and connections to references in other clusters indicate the degree of connectivity within and with other clusters. The co-citation network shown in Figure 6 includes three clusters: the red, green, and blue clusters, containing 24, 22, and 21 references, respectively.

The red, green, and blue clusters, with 804, 631, and 1,040 citations, respectively, were the most significant clusters with the most citations. As shown in Figure 6, there are three clusters (groups) for highly-cited references:

Red Group (Cluster): The most influential document in this group, with 188 citations, is the book *Cognitive Reliability and Error Analysis Method (CREAM)* by Dr. Erik Hollnagel. This cluster includes methods of human error analysis (CREAM), SPAR-H, HEART, human reliability analysis in nuclear power plants, human reliability analysis based on models, and expert models focusing on human reliability analysis.

Green Group (Cluster): This group can be described as the *human error cluster in the marine industry*, as its main focus is on human reliability analysis studies in the marine industry. The most influential source in this group, with 60 citations, is related to a fuzzy modeling application of the CREAM methodology for human reliability analysis. Additionally, the cluster includes CREAM, human error reduction methods, human error modeling, and human error in process industries.

Blue Group (Cluster): This cluster includes practical evaluations of human reliability, validation of the THERP, HEART, and JHED techniques, and human error studies in industrial facilities and the aviation industry. James Reason's book Human Error received the most citations, with 185.

Research Fields Identification and Research Trends Evolution

Keywords are an essential element provided by authors to convey the main content of their articles. The significance of author keywords lies in their role as topics, concepts, or methods authors use to present and communicate their research to the scientific community.[18] The co-occurrence network of author keywords offers an additional perspective on the themes in the field of human error, highlighting the keywords that frequently co-occur in this area.

There are several methods for data mapping, with multidimensional scaling and clustering techniques being the most commonly used. In this research, the clustering method was employed to provide a clearer picture of the human error field.[22] Only keywords that occurred at least five times were selected for the co-trend analysis map to focus on the main themes, highlighting the research topics. As a result, 55 keywords were extracted from 8 clusters based on the keyword frequency threshold. The keyword co-occurrence network for human error clusters is shown in Figure 7. Nodes and larger font sizes indicate more frequent keyword usage. Figure 7 illustrates the concepts and communication distances between them, with the relative size of nodes reflecting keyword frequency. As seen, concepts such as "human error," "human reliability analysis," and "human reliability" are the most frequently used keywords, with frequencies of 196, 113, and 64, respectively.

Figure 7 displays eight clusters. In this map, each color represents a distinct cluster. The keyword color in each cluster was chosen as the cluster name to indicate its thematic classification. The keywords were grouped into categories, each represented by a different color, corresponding to the following themes:

(●) Cluster 1 with 11 keywords, which is also the largest cluster: ergonomics (5), fault tree analysis (6), human error (196), human error assessment (6), human factors (45), human reliability assessment (26), maintenance (11), quality (5), reliability (22), risk assessment (18), and risk management (8).

(●) Cluster 2 with 10 keywords: fmea (5), human error (29), human reliability (64), interval type-2 fuzzy sets (5), maritime safety (13), risk analysis (12), SHERPA (6), situation awareness slim (5), and THERP (5).

(●) Cluster 3 with 9 keywords: hra (9), human error data (5), human factor (20), human performance (7), (7),

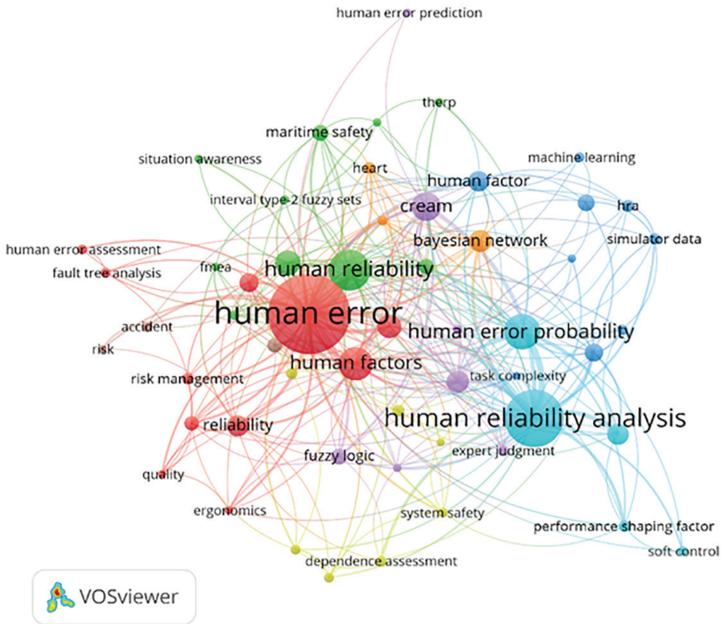

Figure 7: Keyword Co-Occurrence Cluster in Human Error Articles

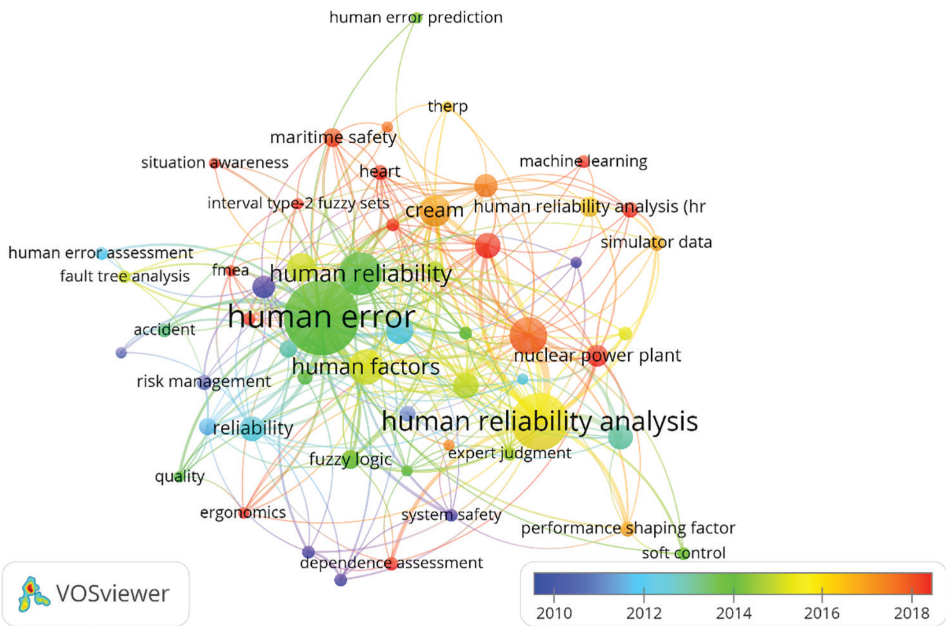

Figure 8: Temporal Evolution of Research Keywords Based on Average Publication Year

human reliability analysis (hra) (15), machine learning (15), nuclear power plant (6), simulator data (17), and task complexity (5).

(●) Cluster 4 with 7 keywords: accident analysis (5), dependence assessment (7), error analysis (6), hfacs (8), human error analysis (9), system safety (6), and task analysis (6).

(●) Cluster 5 with 7 keywords: analytic hierarchy process (5), CREAM (35), expert judgment (7), fuzzy logic (13), human error prediction (5), performance shaping factors (23), and safety assessment (6).

(●) Cluster 6 with 5 keywords: human error probability (50), human reliability analysis (113), performance shaping factor (8), probabilistic safety assessment (22), and soft control (6).

(●) Cluster 7 with 3 keywords: Bayesian network (23), HEART (8), and spar-h (6).

(●) Cluster 8 with 3 keywords: accident (7), risk (5), and safety (11).

In addition, for further analysis of the research topics, Figure 8 presents the evolutionary process and research frontiers in human error studies and the temporal evolution of research keywords based on the average publication date for publications in which the keywords appeared in human error research. VOSviewer software automatically determines the most suitable time frame for the 55 keywords based on the publication time, such as the average year of publication for each keyword. The main research topics can be identified and summarized based on the frequency of occurrence of keywords over time.

Generally, studies in the industrial human error area encompass maintenance, construction, maritime, air traffic control, nuclear power plants, process safety, and nuclear facilities. Due to incomplete keyword data from 1980 to 1991, the analysis was conducted from 1991 to 2022. According to Table 7, most studies have focused on safety issues and occupational accidents. In the 1990s, keywords such as risk assessment and safety received increased attention. Gradually, during the 2000s and 2010s, studies shifted toward risk and accident assessment, the use of human error methods, unsafe practices, artificial intelligence, and related topics. In the third decade, more emphasis was placed on human error detection methods, such as HEART, THERP, SHERPA, Fuzzy CREAM, Spar-H, and probability estimation methods, with Bayesian networks receiving greater attention.

Conclusion

The current study used a scientometric approach to investigate the scientific structure of research in the industrial area of human error. It analyzed scientific publications on human error from the WoS citation database from 1980 to 2022. In total, 845 original and review research articles were included. This study provides insights into the evolution of industrial human error research over the past four decades.

This article's findings, through scientometric analysis, examine trends in previous years and the most influential authors, institutions, countries, journals, and research works, thereby contributing to the body of knowledge on human error.

A key finding of this study is that scientific production has increased from an average of 2.8 articles per year (82 articles) between 1980 and 1990 to 1.33 articles per year (331 articles) in the fourth decade (2010–2019). This upward trend in scientific production

Table 7: Analysis of Keyword Trends in Industrial Human Error from 1991 to 2022

	1991-2000		2001-2010		2011-2022	
	Keyword	**Start year**	**Keyword**	**Start year**	**Keyword**	**Start year**
1	Maintenance	2000	CREAM	2006	Bayesian network	2014
2	Risk assessment	1992	Fuzzy logic	2006	Maritime safety	2014
3	Probabilistic safety assessment	1999	Accident	2002	Risk analysis	2013
4	Safety	1991	Fault tree	2002	Nuclear power plant	2013
5	Construction	1992	Probabilistic safety	2004	HEART	2016
6	Human Performance	1992	Risk management	2002	THERP	2014
7	Safety assessment	1995	Accident analysis	2010	Dempster-Shafer evidence theory	2017
8	Taxonomy	2000	Human error prediction	2008	Fmea	2015
9	Accident investigation	1999	Man-machine interface	2002	Hep	2016
10	Cognitive model	1997	Unsafe act	2009	SHERPA	2013
11	Decision-making	1998	Air traffic control	2002	Slim	2013
12	Expert judgement	1998	Analytic hierarchy process	2007	Soft control	2011
13	Maritime accidents	1998	Bayesian belief network	2008	Spar-h	2018
14			Machine learning	2009	Dematel	2020
15			Marine accidents	2005	Fatigue	2011
16			Operator error	2006	Fuzzy CREAM	2018
17					Marine engineering	2013
18					Nuclear facilities	2015
19					Process safety	2016

highlights the growing significance of human error in occupational accidents and its application in the industrial field. Notably, between 2016 and 2021, there was a significant surge in published articles, which showed a continuous increase. The number of articles produced during these years accounts for nearly half of the publications from 1980 to 2022.

The top authors in industrial human error were Dhillon BS (with the most publications), followed by Akyuz E and Kirwan B. Three top researchers were affiliated with universities in South Korea, with the following ranks held by Canada, Turkey, France, and Australia. The study of the geographical distribution of countries revealed that the majority of research came from the two developed countries, the United States and the People's Republic of China. Developing countries like Iran and Turkey have made significant contributions in recent years. According to the institutions, the Korea Atomic Energy Research Institute in South Korea made the most substantial scientific contributions to human error related to industry. The following highest rankings belonged to Istanbul Technical University (Turkey) and Memorial University of Newfoundland (Canada).

Memorial University of Newfoundland in Canada had the highest number of citations (693), followed by Cornell University and Vanderbilt University in the USA. Regarding international cooperation, three institutions—Memorial University of Newfoundland, the University of Tasmania, and the Korea Atomic Energy Research Institute—had the most links and international collaborations.

By analyzing the co-occurrence of human error keywords, it was observed that studies in the field of industrial human error have generally focused on maintenance, construction, maritime, air traffic control, nuclear power plants, process safety, and nuclear facilities. Most studies have emphasized safety issues and occupational accidents, with keywords such as 'risk assessment' and 'safety' receiving more attention in the 1990s. Between 2000 and 2010, research shifted towards risk and accident assessment, human error methods, unsafe practices, and artificial intelligence. In the third decade, more studies focused on human error detection methods, such as HEART, THERP, SHERPA, Fuzzy CREAM, and Spar-H, as well as probability estimation methods, with Bayesian networks being increasingly emphasized.

The analysis of the results identified three leading and active journals in industrial human error research: *Reliability Engineering & System Safety*, *Safety Science*, and *Microelectronics and Reliability*. After analyzing highly cited sources, a total of 67 highly cited references out of 19,880 human error references were identified, which can be considered the primary intellectual foundations of industrial human error research. Gerhart B's article, published in 2000, had the highest number of citations (315). In addition, four articles had more than 200 citations. A few publications accounted for many self-citations, indicating that review articles will likely receive more citations.

This study can be valuable for researchers in human error studies within industries. It can also assist young researchers in gaining valuable insights into human error research. Furthermore, the collaboration of specialists from various fields, such as nuclear experts, marine sciences, oil and gas industries, or ergonomics, can help enrich scientometric research in this area.

One of the shortcomings of research in this field is the relatively limited attention given to the role of artificial intelligence in reducing human errors compared to its application in medical errors. Artificial intelligence is widely used to diagnose various conditions in the medical field.[23] A review study by Sethu et al. explored the use of artificial intelligence in detecting and reducing human errors in nuclear power plants. They report that the advent of artificial intelligence technology will increase the margin of safety in these industries.[24] Another study by Gursel et al. showed that generative adversarial networks improve anomaly detection performance.[25]

Therefore, it is recommended that artificial intelligence, machine learning, and deep learning be more extensively discussed in future studies to identify, diagnose, and prevent human errors, particularly in process industries. Moreover, while most studies have focused on evaluating human errors in various sectors, there is a noticeable gap in research addressing preventive solutions for human errors. Studies in this area are strongly recommended.

Limitations of the Study

This study was conducted solely on articles indexed in the WoS database. Therefore, it is recommended that similar research be conducted using records from the Scopus and PubMed databases. Combining the resulting information can present a more comprehensive picture of the studies conducted in this field.

Authors' Contribution

Each of the authors contributed equally to this research.

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References

1 T Akhtar, R Yeganeh, Z Damiri. Identification and Assessment of Human Errors of Overhead Crane Operators using SHERPA and SPAR-H Techniques, J. Occup. Hyg. Eng. Vol. 8 (2022) 59–68. URL: http://johe.umsha.ac.ir/article-1-679-en.html.

2 A Babaei-Pouya, Z Pajohideh, MF Arefi. Identification and risk assessment of midwife error in the labor using systematic human error reduction and prediction approach, J. Heal. Saf. Work. 11 (2021) 737–750. URL: http://jhsw.tums.ac.ir/article-1-6585-en.html.

3 Jahangiri M, Hoboubi N, Rostamabadi A, Keshavarzi S, Hosseini AA. Human Error Analysis in a Permit to Work System: A Case Study in a Chemical Plant. Saf Health Work. 2016;7(1):6-11. doi: 10.1016/j.shaw.2015.06.002. PMID: 27014485; PMCID: PMC4792918.

4 M Azhdari, G Monazami Tehrani, A Alibabaei. Investigating the causes of human error-induced incidents in the maintenance operations of petrochemical industry by using HFACS, J. Occup. Hyg. Eng. 3 (2017) 22–30. URL: http://johe.umsha.ac.ir/article-1-220-en.html.

5 AA Garmaroudi, S Mozaffari, M Bahrami, H Alimoradi. Identification, evaluation and prioritization of human errors in the nursing population of the hospital's coronary care unit, Iran Occup. Heal. 18 (2021) 166–179. doi: 10.52547/ioh.18.1.155.

6 Radley DC, Wasserman MR, Olsho LE, Shoemaker SJ, Spranca MD, Bradshaw B. Reduction in medication errors in hospitals due to adoption of computerized provider order entry systems. J Am Med Inform Assoc. 2013; 20(3):470-6. doi: 10.1136/amiajnl-2012-001241. PMID: 23425440; PMCID: PMC3628057.

7 AM Feyer, AM Williamson, DR Cairns. The involvement of human behaviour in occupational accidents: errors in context, Saf. Sci. 25 (1997) 55–65. doi: 10.1016/S0925-7535(97)00008-8.

8 GA Shirali, A Golbaghi, L Nematpour. Comparison of Two Human Error Evaluation Techniques (HET and SHERPA) in Gas Supply Operations using AHP, J. Heal. Saf. Work. 10 (2021) 376–390. URL: http://jhsw.tums.ac.ir/article-1-6413-en.html.

9 L Chen, W Li, J Li, Q Fu, T Wang. Evolution trend research of global ocean power generation based on a 45-year scientometric analysis. Sci. Eng. 9 (2021) 218. doi: 10.3390/jmse9020218.

10 L Khalili, F Mohammadi. Scientometric Analysis of English-language Journals in the Field of Knowledge

and Information Science in Iran Based on Scopus Data. Sci. Res. J. 7 (2021) 197–220. doi: 10.22070/rsci.2020.5329.1368.

11 E Janavi, S Abdi. Scientometric analysis of scientific outputs in the field of media and information literacy, Casp. J. Sci. 8 (2021) 10–21. URL: http://cjs.mubabol.ac.ir/article-1-221-en.html.

12 J Li, F Goerlandt, G Reniers. Mapping process safety: A retrospective scientometric analysis of three process safety related journals (1999–2018), J. Loss Prev. Process Ind. 65 (2020) 104141. doi: 10.1016/j.jlp.2020.104141.

13 J Gao, X Wu, X Luo, S Guan. Scientometric Analysis of safety sign research: 1990–2019, Int. J. Environ. Res. Public Health. 18 (2021) 273. doi: 10.3390/ijerph18010273.

14 L Waltman, NJ Van Eck, ECM Noyons. A unified approach to mapping and clustering of bibliometric networks, J. Informetr. 4 (2010) 629–635. doi: 10.1016/j.joi.2010.07.002.

15 Haghani M, Bliemer MCJ, Goerlandt F, Li J. The scientific literature on Coronaviruses, COVID-19 and its associated safety-related research dimensions: A scientometric analysis and scoping review. Saf Sci. 2020; 129:104806. doi: 10.1016/j.ssci.2020.104806. PMID: 32382213; PMCID: PMC7203062.

16 M Aria, C Cuccurullo. bibliometrix: An R-tool for comprehensive science mapping analysis, J. Informetr. 11 (2017) 959–975. doi: 10.1016/j.joi.2017.08.007.

17 A Rey-Martí, D Ribeiro-Soriano, D Palacios-Marqués. A bibliometric analysis of social entrepreneurship, J. Bus. Res. 69 (2016) 1651–1655. doi: 10.1016/j.jbusres.2015.10.033.

18 Xue J, Reniers G, Li J, Yang M, Wu C, van Gelder PHAJM. A Bibliometric and Visualized Overview for the Evolution of Process Safety and Environmental Protection. Int J Environ Res Public Health. 2021; 18(11):5985. doi: 10.3390/ijerph18115985. PMID: 34199608; PMCID: PMC8199718.

19 H Liu, H Chen, R Hong, H Liu, W You. Mapping knowledge structure and research trends of emergency evacuation studies, Saf. Sci. 121 (2020) 348–361. doi: 10.1016/j.ssci.2019.09.020.

20 Bamel UK, Pandey R, Gupta A. Safety climate: Systematic literature network analysis of 38 years (1980-2018) of research. Accid Anal Prev. 2020; 135:105387. doi: 10.1016/j.aap.2020.105471. PMID: 31838322.

21 A Zarei, I Fasihi, S Karami, A Soltanian, A Giti. Scientific productivity researchers in Hamadan University of Medical Sciences based on Bradford law in Web of Sciences database from start to 2016, Pajouhan Sci. J. 15 (2017) 36–42. URL: http://psj.umsha.ac.ir/article-1-288-en.html.

22 M Sedighi. Application of word co-occurrence analysis method in mapping of the scientific fields (case study: the field of Informetrics), Libr. Rev. 65 (2016) 52–64. doi: 10.1108/LR-07-2015-0075.

23 M Paredes. Can Artificial Intelligence help reduce human medical errors? Two examples from ICUs in the US and Peru, 2009 (2018) 1–12. https://techpolicyinstitute.org/wp-content/uploads/2018/02/Paredes-Can-Artificial-Intelligence-help-reduce-human-medical-errors-DRAFT.pdf.

24 M Sethu, B Kotla, D Russell, M Madadi, NA Titu, JB Coble, et al. Application of Artificial Intelligence in Detection and Mitigation of Human Factor Errors in Nuclear Power Plants: A Review, Nucl. Technol. 2022 (2022) 1–19. doi: 10.1080/00295450.2022.2067461.

25 M Sethu, N Titu, D Hu, M Madadi, J Coble, R Boring, et al. Using Artificial Intelligence to Mitigate Human Factor Errors in Nuclear Power Plants: A Review, Nucl. Eng. Technol. 2022 (2022) 129–141. doi: 10.13182/t124-34339.