Article

Accident Prevention Analysis: Exploring the Intellectual Structure of a Research Field

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Abstract: Accident prevention is of great significance in avoiding or reducing all kinds of casualties and economic losses, and is one of the main challenges for social sustainable development. Hence, it has been an active research field for many decades around the world. To master the research status of accident prevention, and explore the knowledge base and hot trends, 1294 papers from the WOS retrieval platform SCIE and SSCI databases from 1990 to 2021 were selected as data samples. Co-occurrence analysis, co-citation analysis, co-authorship analysis, and keyword analysis were performed on the literature on accident prevention research with bibliometric analysis methods. The study showed that the United States ranked first in the number of publications of any country/region and Georgia Inst Technol ranked first in the number of institutional publications. System analysis and accident model establishment, analysis of construction accidents, road accident prevention, and safety culture and safety climate are the knowledge base in the accident prevention studies and the core journals in this field are *Safety Science*, *Accident Analysis and Prevention*, *Pediatrics*, and *Reliability Engineering & System Safety*. There are four major research hotspots in accident prevention studies: routine accident prevention, model-based research, systems analysis and accident prediction, and occupational safety and public health research. At present, the basic theory and structural system of accident prevention research have been basically established, with many research directions and a wide range of frontier branches. Safety management, public safety, Bayesian networks, and simulation are the research frontiers of accident prevention.

Keywords: accident prevention; safety analysis; knowledge base; intellectual structure; bibliometric analysis

1. Introduction

Accident generally refers to the parties in violation of laws and regulations or accidental death, disease, injury, damage, or other serious losses caused by negligence, such as traffic accidents, production accidents, medical accidents, and self-inflicted accidents [1,2]. With the development of the world economy, as mining, chemical industry, construction, transportation, and other industries continue to develop, and the scale of production continues to expand, various types of accidents occur more and more frequently, resulting in numerous casualties and huge property losses, which have serious adverse social impacts. For example, a magnitude 9.0 earthquake in 2011 caused the leakage of radioactive substances from the Fukushima Nuclear Power Plant, and many people suffered from cancer [3]. In July 2021, there was another nuclear waste leak at the Fukushima Nuclear Power Plant. In 2016, two people were killed and six seriously injured because of an explosion

and a fire at the chemical plant in BASF, Germany [4]. In 2018, a fire broke out during the operation of Rail Transit Line 21 in Guangzhou, China, resulting in a sudden collapse during the rescue, resulting in three deaths and a direct economic loss of 100,898 million CNY. In November 2021, 51 people were killed when coal powder caught fire and triggered a methane explosion in a mine in the Russian state of Kemerovo. The main reasons for all kinds of accidents are the lack of safety awareness of relevant personnel, inadequate emergency treatment of emergencies and the need for various regulatory measures to be improved. Obviously, the impacts on social sustainable development that have been caused are incalculable [5]. Therefore, it is necessary to propose effective accident prevention measures according to the relevant requirements of safety production and the actual situation of each industry.

Accident prevention, as the first research route of safety science, studies safety from accidents and formulates safety laws from the facts of the accident [6]. The research on accident prevention takes casualty accidents as the object and discusses the accident cause factors and their interrelation, the accident cause factor control, etc. There is a lot of research about accident prevention. On the personal level, Minhad et al. studied the influence of emotions on driver safety from the perspective of individual physiological conditions [7]. Liang et al. explored the social contagion effect of unsafe behavior of construction workers using system dynamics and modeling [8]. On the management level, David presented a more balanced and comprehensive method of workplace safety management by comparing two different safety management standards [9]. Hanninen managed maritime traffic safety and made decisions through the Bayesian network model [10]. From the point of view of front-line production, several kinds of sensors were used to monitor the condition of personnel in real time to effectively ensure personnel safety and prevent accidents [11,12]. Wang et al. summarized China's achievements in accident prevention measures in the industrial field [13]. There are also many methods to perform accident analysis [14]. The Poisson–Tweedie model [15] and HFACS-HC model [16] can analyze the time, place, and causes of accidents. Cost–benefit analysis (CBA) methods can be used to estimate the costs and benefits of accident prevention measures [17]. Bayesian networks can establish interrelationships between the different causes of accidents [18]. It can be seen that the research on accident prevention has been continuously refined throughout the process, from its germination and theory formation to theoretical refinement and applied practice. With the rapid advancement of research and related results of the output, the directions have been expanded, which to a certain extent makes the division of accident prevention research clearer, but to have a comprehensive understanding of accident prevention research from macro and micro levels at the same time brings difficulties for academia and industry.

At present, the reason why few studies have been conducted to systematically describe the topic of accident prevention is probably that this field involves many disciplines, a wide range, and a large span. Scholarly studies are time-consuming and laborious when dealing with this research and the results are often somewhat subjective. With the development of computer technology and literature digitization technology, the methods of bibliometrics have become an effective way to explore the knowledge base, research hotspots, evolutionary paths, and their impacts in the research field [19]. Research exploring the characteristics of domain topics by mining the domain research topics has been involved in various fields. In the field of safety science research, bibliometrics has been used in transportation construction [20,21], biosafety [22,23], nuclear safety [24], ergonomics [25], energy safety [26,27], safety culture [28], progress safety [29], system safety [30], etc. It plays a crucial part in developing research and provides a basis for further research by scholars [31]. To better understand the current situation and the trend of international research in accident prevention studies, this paper intends to analyze the entire field of research from a bibliometric perspective by drawing a scientific knowledge map, and to systematically study the following questions through visualization: (1) Which research networks are most active in the field of accident prevention? (2) What is the knowledge

base and what are the research methods in the field of accident prevention? (3) What are the themes and developmental trends of accident prevention research?

2. Materials and Methods

2.1. Sample Collection and Cleaning

The literature related to accident prevention can be retrieved from the Web of Science, which is widely considered to be one of the most comprehensive and highest-quality English literature databases [19]. Science Citation Index Expanded (SCI-EXPANDED)-1900 and Social Science Citation Index (SSCI)-1900 in the Web of Science Core Collection were selected as the target databases for this paper.

Full-text search is the search strategy that can best reflect the actual situation. However, it is obviously impossible to complete because of the huge period and coverage of this research. The word "accident prevention" was used for the search, which would exclude related papers on similar topics such as "injury prevention" and "loss prevention". The retrieval process of the data is shown in Table 1.

Table 1. Overview of sample for analysis, 1902~2021.

NO.	Retrieval Strategies	Sample	Retrieval Quantity	Years	Sample Used in Each Section
1	Topic = ("prevention")	A	738,582	1902~2021	Not used in analysis
2	Topic = ("accident")	B	69,290	1902~2021	Not used in analysis
3	Topic = ("accident") and Topic = ("prevention")	A∩B	5117	1902~2021	Not used in analysis
4	Topic = ("accident prevent *")	~A, ~B	1856	1902~2021	Section 3.1.1
5	Topic = ("accident prevent *")	~A, ~B	1489	1990~2021	Not used in analysis
6	Topic = ("accident prevent *") and Document Types = (Article OR Review) and Language = (English)	~A, ~B	1294	1990~2021	Section 3.1.2 Sections 3.2–3.4

Notes: ~A: articles from the sample are excluded; A∩B: articles found both in sample A and B; *: the root-related variants of the word.

As can be seen from Table 1, the literature was retrieved by retrieval strategy 4, which were selected as data samples for Section 3.1.1 analysis. A total of 1329 articles were retrieved among the 1489 papers retrieved by strategy 5, accounting for 89.25% of the total literature, and these are the most frequent type of literature. Reviews ranked second, with 87 articles (5.84%). A total of 1294 English articles (retrieval strategy 6) were selected as data samples for Sections 3.1.2 and 3.2–3.4

There are still some shortcomings in using this sample for research. The literature included in the Web of Science database is mainly in English, so the research based on this sample only represents the number of English-language journals, not the actual global total. Furthermore, because the papers included in the early SCI and SSCI are not complete, and the number of citations has expanded rapidly in the past two decades, the number of publications and citations cannot fully represent the actual situation and real developmental trend.

2.2. Method

Due to the large amount of relevant literature involved, it is necessary to analyze the literature with the help of appropriate tools and methods to achieve a quantitative and visual analysis of the literature in the field of accident prevention research. Bibliometrics refers to the quantitative analysis of all knowledge carriers by means of mathematics and statistics [32]. By analyzing the change in the publications and studying the regional distribution, internal quantitative relationships and change patterns of information, bibliometrics

can effectively determine the research trends in a certain field and predict its developmental direction [33].

Adopting the analysis methods of bibliometrics and visualization, the retrieved literature was co-occurrence analyzed, cluster analyzed, co-citation analyzed, and intermediary centrality calculated, and presented in the form of visual graphics by the software VOSviewer and CiteSpace, which can help to derive the research hotspots in the accident prevention studies, as well as the main content and frontiers of related research. In this way, the basis of the knowledge and the developmental trend in the accident prevention field can be explored [34]. The operation process is shown in Figure 1.
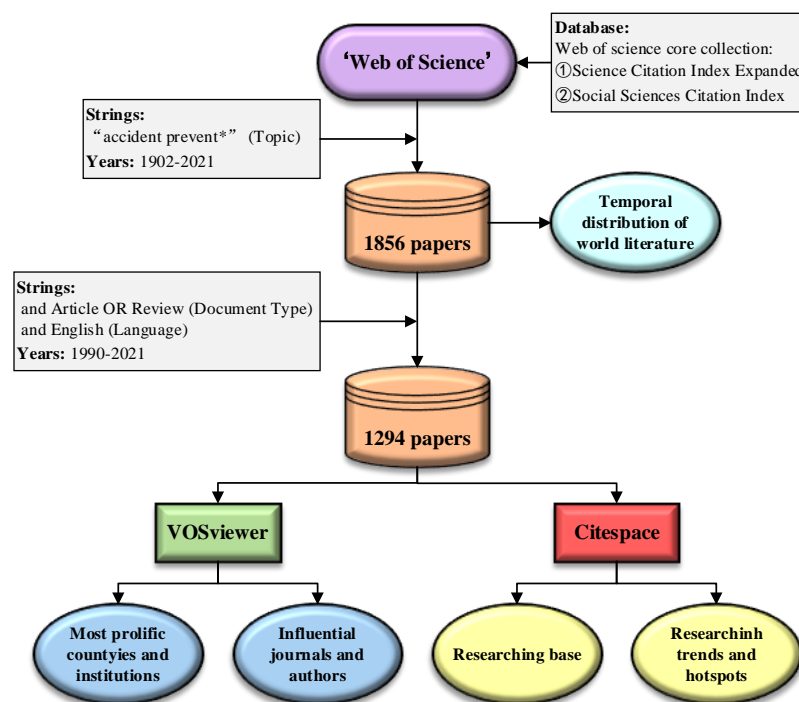

Figure 1. The procedure and methods used in the accident prevention study. Notes: *: the root-related variants of the word.

3. Result and Discussion

3.1. Time Distribution of the Literature

3.1.1. Time Distribution of World Literature

To have a more complete and macroscopic understanding of the temporal distribution of the world literature, this part selects data from a sample of 1856 articles published from 1902 to 2021 for the analysis, which visualizes the characteristics of the temporal distribution of research on accident prevention and the degree of attention it has received. The overall trend shows that the number of publications in this field has been increasing year by year. The number of total publications and the number of annual publications can be seen in Figure 2. According to the rate of change in the number of posts, the developmental progress of accident prevention studies can be roughly divided into four stages.

Exploratory stage (1902–1965): In this stage, the annual publications in this field were small, with a maximum of only nine papers. One reason for this is that the literature collected by SCI and SSCI before 1970 is incomplete and cannot fully represent the real research situation. Another reason is that the research on accident prevention had only just started during this stage. During this period, the topics of the literature were accident prevention in industrial and occupational health. The earliest article that appeared was Accident prevention and industrial hygiene by Heffter from Germany in 1902 [35]. The literature that appeared in the following years focused on industrial and medical safety. It can be assumed that the development of the second industrial revolution, which not

only improved productivity, but also led to various types of accidents in industrial production processes. Therefore, the early research focused on industrial production and medical health.

Theory formation stage (1966–1990): Between 1966 and 1990, the publication of literature had obviously increased compared with the last stage, and the annual publications were more regular, among which the number of publications in 1966 was as high as 21. Accident prevention research accounted for a large proportion of chemical production. Some industrialized countries conducted a lot of scientific research on production safety, and the ideas and theories with system safety theory as the core were basically formed, and safety system engineering was produced in this stage. Meanwhile, the research on accident prevention began to expand from industry and medicine to chemical, transportation, construction, behavior, etc.

Stable development stage (1991–2010): With the improvement of the economy and productivity of countries all over the world, the major discipline of occupational safety and health personnel training came into being, while the demand for personnel engaged in the design, consultation, management, and inspection of occupational safety and health was increasing. Safety science began to become a discipline. Many institutions established independent teaching and research units in safety science, such as the Center for Accident Prevention at Monash University, the Department of Safety and Health Sciences at the University of Illinois, and the Department of Fire and Safety Engineering at the University of Oklahoma. In addition, *Safety Science*, *Journal of Safety Research*, *Reliability Engineering & System Safety*, and other related fields of international journals had gradually matured.

Rapid development phase (2011–2021): The number of publications grew rapidly with an average annual growth rate of more than 30 papers. One reason is the increase in the number of journals included in SCI and SSCI databases in recent 20 years. In addition, the breadth and depth of accident prevention research had increased tremendously, and the tools and methods of research had changed from simple accident investigation to the use of various mathematical models and simulations. It reflected the increasing attention of scholars to accident prevention, and the related research in the field was increasing and entering a rapid developmental stage.
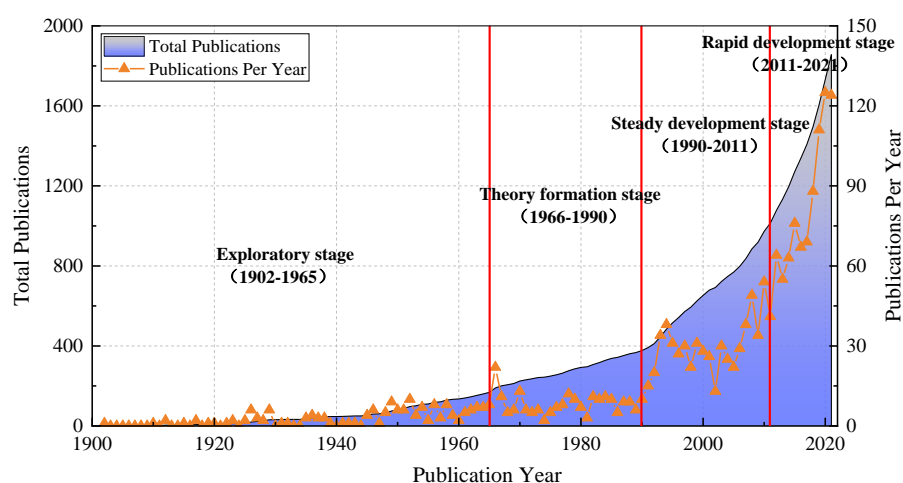

Figure 2. The world's annual publication trend.

3.1.2. Time Distribution of National Literature

According to the statistics of the literature sources, the USA, China, the UK, and Australia rank in the top four by number of publications. The time distribution of the literature in the above four countries can be analyzed by a bubble chart, and the bigger the bubble, the greater the number of the published literature. Comparing the developmental pattern of each country (see Figure 3), the number of articles published in three English-speaking countries, the USA, the UK, and Australia, has been high, and the number of articles pub-

lished in China has been very small until nearly 20 years ago. One reason is that the SCI and SSCI database mainly cites English periodicals, which favors English-speaking countries. The USA and the UK were the first to have a stable number of publications in accident prevention since 1990, and the research process of the two countries was similar, with the first period focusing on accidental injury and occupational safety, and the latter period shifting accident prevention from preventing external injuries to ensuring the internal safety of the system. Some safety assessment methods and accident prevention measures were put forward from the point of view of management and technology [36]. Very little literature was published in Australia annually. Initial research on accident prevention mainly focused on preventing the accidental injuries of children, and then gradually developed to include construction, transportation, and environmental aspects. Loosemore first proposed that psychological conditions would have an impact on construction safety [37]. In 2015, 14 papers were published, which was the highest point of the post volume in Australia, and the research was focused on the construction and operation of roads and railways. China, which started publishing in 2003, was the most recent to start research in the field of accident prevention, but has had the fastest growth rate and a wide range of research. In 2015, it surpassed the USA to become the country with the most research in this field.
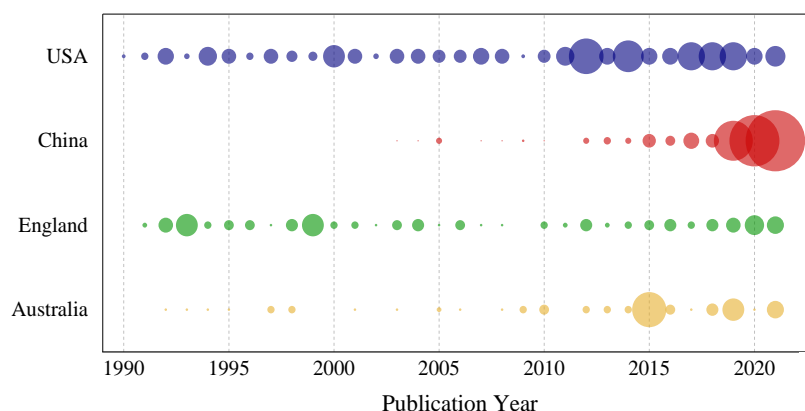

Figure 3. Publication trend of the top 4 countries (USA, China, the UK, Australia).

3.2. Spatial Distribution Map of the Literature

3.2.1. Country/Region Distribution

The statistics and study of the spatial distribution of literature sources can reveal the research strength and influence of individual countries/regions on related topics, which can help further fruitful research and scientific research co-operation. In addition, the spatial distribution of a certain field also shows the level of attention to the topic in the spatial distribution. From the search results, the papers on accident prevention research analyzed are from 77 countries/regions The top 10 countries are selected by a total number of publications (see Table 2 for details), and the world map is plotted with publications and H-index (Figure 4). The top three countries with the largest number of publications are the USA (309), China (170), and the UK (129), accounting for 36.6% of the total publications. In terms of regional distribution, most of the papers originated from developed countries, and European and American countries published articles of high quality. China is the developing country with the highest volume and its ACI and H index are in the first place, indicating that China pays more attention to the accident prevention research, and the quality of research results is high. The USA, China, and the UK are the top three countries by the number of publications and among the top 10 countries by ACI, which is more influential in the studies of accident prevention. Although Canada ranks seventh in the number of articles published, its ACI exceeds 20, indicating that Canada's research in this field is more valuable and widely noticed.

Table 2. Top 10 Countries that publish the top 10 in accident prevention studies, 1990–2021.

Rank	Country	Region	TP	Percentage	ACI	H-Index	Total Link Strength
1	USA	North America	276	21.33%	29.96	44	44
2	China	Asia	189	14.61%	13.15	28	54
3	UK	Europe	119	9.20%	28.38	30	50
4	Australia	Oceania	73	5.64%	27.05	24	29
5	South Korea	Asia	71	5.49%	9.93	12	8
6	Brazil	South America	63	4.87%	7.67	11	8
7	Canada	North America	63	4.87%	23.06	24	15
8	Italy	Europe	52	4.02%	19.58	17	24
9	Norway	Europe	41	3.17%	31.32	18	24
10	Japan	Asia	40	3.251	5.4	8	14

Notes: TP: total publications; ACI: Average Citations per Item.

The countries and regions that are actively co-operating and those that are at the forefront of international cooperative research can be found through the analysis of the extent of international co-operation in accident prevention studies. These results will help scholars from various countries to find partners and further carry out academic exchanges. International research is an important means by which to share professional knowledge and exchange ideas [38,39].
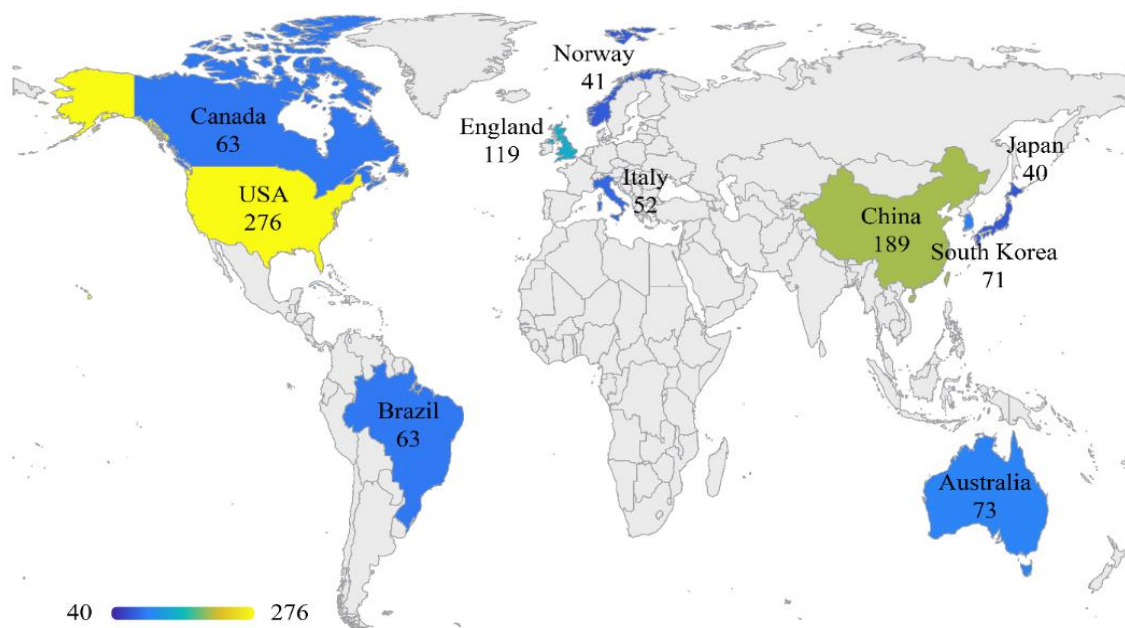
Figure 4. Production of the top 10 countries.

Through the VOSviewer analysis of the retrieved data, the cooperative relationship between countries was analyzed, and the minimum number of posts was set to five, and a total of 41 national information mapping co-operation networks were obtained (see Figure 5). In the figure, each node represents a country, the node size represents the number of posts, and the connection thickness between nodes represents the intensity of co-operation between countries.
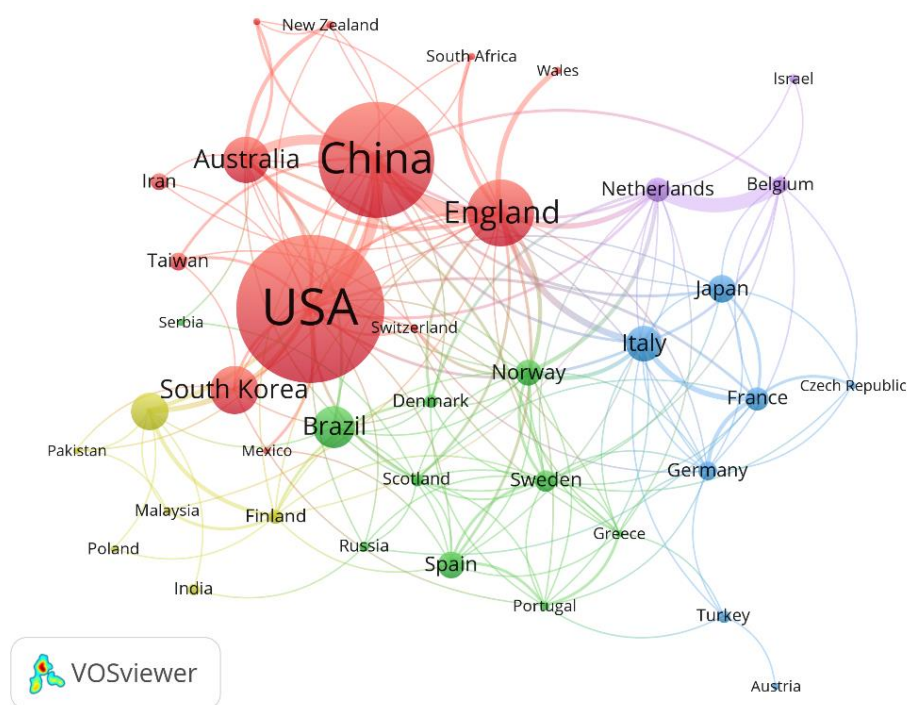
Figure 5. Co-operation of countries in accident prevention studies.

Five distinct clusters can be seen in Figure 5, with China having the highest total linkage co-operation intensity with USA and the UK, and also co-operating frequently with each country. In addition, co-operation between the Netherlands and Belgium is also frequent. Most of other inter-country co-operation is clustered geographically, with one cluster for European countries and one cluster for American countries. It can be concluded that at present, the global research in the field of accident prevention is still uneven and the gaps are obvious, which is mainly reflected in the fact that more economically developed countries and regions pay more attention to personal health and safety.

3.2.2. Disciplinary Distribution of the Literature

Analysis of the disciplinary distribution of the literature is helpful to master the discipline structure of this research field. CiteSpace shows that the sample literature is distributed in 111 different disciplines and the statistics of the top 10 disciplines regarding the number of publications can be seen in Table 3. Centrality is the central degree, and the node is considered to be the key hub (turning point) in the network when the center degree is more than 0.1. The percentage represents the proportion of publications in the discipline. According to Table 3, the three disciplines with high centrality are ergonomics (0.39), social sciences (0.37), engineering and chemical (0.24), which are the important parts of the accident prevention research. In addition, the engineering category has the largest number of posts, with 562 articles, accounting for 43.43%, the second and the third being public, environmental and occupational health (22.72%), and engineering, industrial (14.30%), which represent the main research objects in the field of accident prevention. Moreover, the research in the field of accident prevention also involves management, medicine, economics, chemistry, social sciences, computer science, physics, and other disciplines, which are affected by many factors. In conclusion, the accident prevention literature is widely distributed and is a multidisciplinary cross-sectional research field.

Table 3. The top 10 disciplinary categories in accident prevention studies, 1990–2021.

Rank	TP	Centrality	WOS Categories	Percentage
1	562	0	Engineering	43.43%
2	294	0.12	Public, environmental and occupational health	22.72%
3	185	0.16	Engineering, industrial	14.30%
4	147	0.18	Transportation	11.36%
5	143	0.02	Operations research and management science	11.05%
6	127	0.39	Ergonomics	9.81%
7	93	0.24	Engineering and chemical	7.19%
8	85	0.37	Social sciences	6.57%
9	84	0.04	General and internal medicine	6.49%
10	83	0.08	Engineering, civil	6.41%

Note: TP: total publications.

3.2.3. Institutional Distribution of Literature

An analysis of the collaboration of institutions in the accident prevention studies provides insight into their academic productivity and connections with other academic, governmental, and industry institutions. The literature data retrieved involved 1710 institutions, and Table 4 shows the information on the 10 institutions with the most published papers. The top 10 institutions are all universities, which indicates that universities are the mainstay in accident prevention studies. More than half of the institutions' country affiliations are from Europe and America, indicating that Europe and America are in a leading position and are the main contributors to the research in this field. Among the top 10 institutions, the institutions with the highest volume of publication are Georgia Inst Technol (15), Univ Sao Paulo (14), and Tsinghua Univ (14), and the highest average citations are Norwegian Univ Sci & Technol (34.57), Univ Nottingham (30.25), and Delft Univ Technol (28.46). The number of posts is not related to the number of citations. Although Univ Sao Paulo in Brazil publishes a large number of articles, it is cited less, indicating that the content of the organization's post is not as highly valued. Univ Nottingham is in 8th place, but its average citations are high, which indicates that its publications are of high research value.

Table 4. Top 10 institutions in accident prevention studies, 1990–2021.

Rank	Institution	Country	TP	Total Link Strength	Sum of Times Cited	Average Citations
1	Georgia Inst Technol	USA	15	0	413	27.53
2	Norwegian Univ Sci & Technol	Norway	14	1	484	34.57
3	Tsinghua Univ	China	14	5	204	14.57
4	Univ Antwerp	Belgium	14	11	374	26.71
5	Univ Sao Paulo	Brazil	14	1	84	6.00
6	Delft Univ Technol	Netherland	13	12	370	28.46
7	China Univ Min & Technol	China	12	2	71	5.92
8	Huazhong Univ Sci & Technol	China	12	4	169	14.08
9	Univ Nottingham	UK	12	0	363	30.25
10	Hansung Univ	South Korea	11	0	156	14.18

Notes: TP: total publications.

After screening, the software VOSviewer was used to generate the cooperative network diagram of the main research institutions (see Figure 6). The nodes' size in the figure represents the number of publications, and the strength of institutional co-operation can be seen from the width of the connection. As shown in Figure 6, it can be divided into seven clusters according to the co-operation of each research institution.
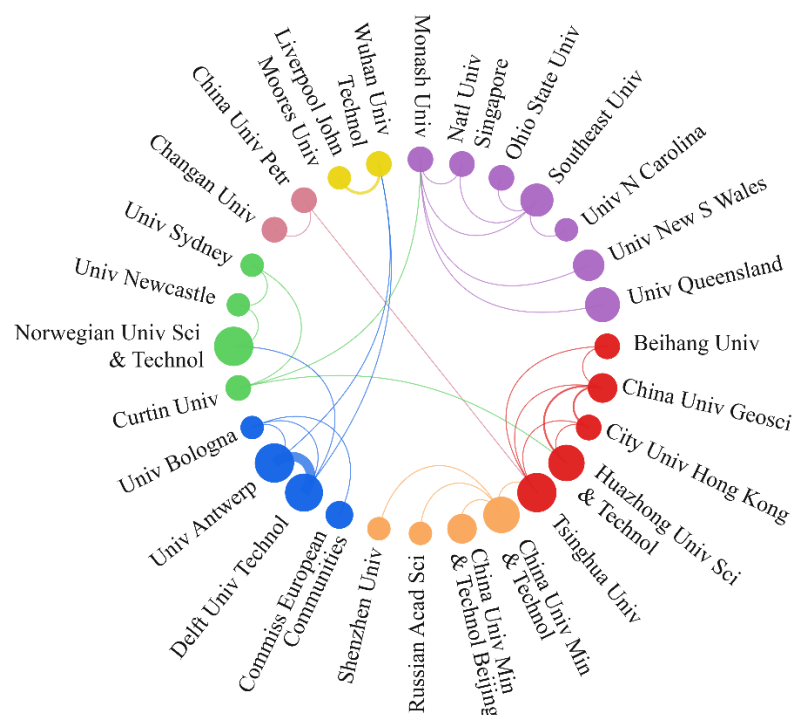
Figure 6. Co-operation of institutions in accident prevention studies.

In the red clustering dominated by Tsinghua University, there is much research on unsafe human behavior, which mainly focuses on the role of human behavior in accident prevention studies. In the green cluster led by the Norwegian University of Science and Technology, accident prevention in engineering such as construction and transportation dominate. In a survey of offshore oil operators, Rundmo found a positive correlation between risk perception and risk behavior in a survey of offshore oil operators, but risk perception could not predict risk behavior [40]. Then, together with Nordfjaern, the relationship between risk perception and traffic risk was discussed [41]. In the purple clustering led by the University of Queensland, the institutional research is mainly on roads and medicine. As can be seen in Figure 5, each cluster consists of institutions from multiple countries, which leads to the conclusion that current institutional collaboration regarding the field of accident prevention is dominated by the relevance of the research content, followed by geographical aggregation.

3.2.4. Journal Distribution

As a medium, academic journals can disseminate academic information, publish academic research results, and play an intermediary role in connecting the research subjects between the upstream and downstream of the research process. Different academic journals can reflect different research fields and the quality of the literature.

Table 5 lists the journals with the top 10 number of publications, including the corresponding total number of publications (TP), average citations (ACI), type of journal (Citation Index), and impact factor. Among them, 114 papers were published in *Safety Science* (accounting for 6.56%), far more than other journals. The top three journals ranked by average citations are *American Journal of Public Health*, *Safety Science* and *Journal of Safety Research*, with impact factors of 9.308, 4.877 and 3.487, respectively, indicating that these three journals are more influential in prevention research and that their articles are borrowed and studied by many scholars. In addition, the journals related to the field of accident prevention are included in both SCIE and SSCI, indicating that the research is involved in both social sciences and natural sciences, and accident prevention is an important research topic in various industries.

Table 5. Top 10 journals in accident prevention studies, 1990–2021.

Rank	Journal Title	TP	ACI	Citation Index	Impact Factor
1	*Safety Science*	114	41.62	SCIE	4.877
2	*Accident Analysis and Prevention*	60	36.88	SSCI	4.993
3	*Journal of Loss Prevention in The Process Industries*	42	18.12	SCIE	3.66
4	*Process Safety and Environmental Protection*	19	31.74	SCIE	6.158
5	*Reliability Engineering & System Safety*	19	27.53	SCIE	6.188
6	*Journal of Safety Research*	18	37.72	SSCI	3.487
7	*International Journal of Environmental Research and Public Health*	17	7.24	SCIE/SSCI	3.39
8	*International Journal of Occupational Safety and Ergonomics*	17	14.76	SSCI	2.141
9	*Work-A Journal of Prevention Assessment & Rehabilitation*	16	4.25	SSCI	1.505
10	*American Journal of Public Health*	14	63.93	SCIE/SSCI	9.308

Notes: TP: total publications; ACI: Average citations per item.

VOSviewer is used to analyze the distribution of the journals in accident prevention studies, and a journal network graph is generated for screen journals with at least five publications (see Figure 7). The node size represents the number of publications, and the width of the line represents the mutual citation intensity between journals. The figure shows that *Safety Science*, *Accident Analysis and Prevention*, and *Journal of Loss Prevention in The Process Industries* are the top three journals by the number of publications. *Safety Science* has a high level of mutual citation with other journals which indicates that the research scope of the literature in this journal is relatively broad, and that the journals have a high research value. Red and green dominate the clusters, and the largest node in the green cluster is *Journal of Loss Prevention in The Process Industries*, but there are few collaborations with other journals and the nodes in the yellow and blue clusters are of similar size. The blue clusters consist mainly of public health-related journals, such as *American Journal of Public Health*, *Traffic Injury Prevention*, and *Pediatrics*, which publish research from the perspective of personal injury. Journals in the blue cluster mostly publish research on engineering safety.
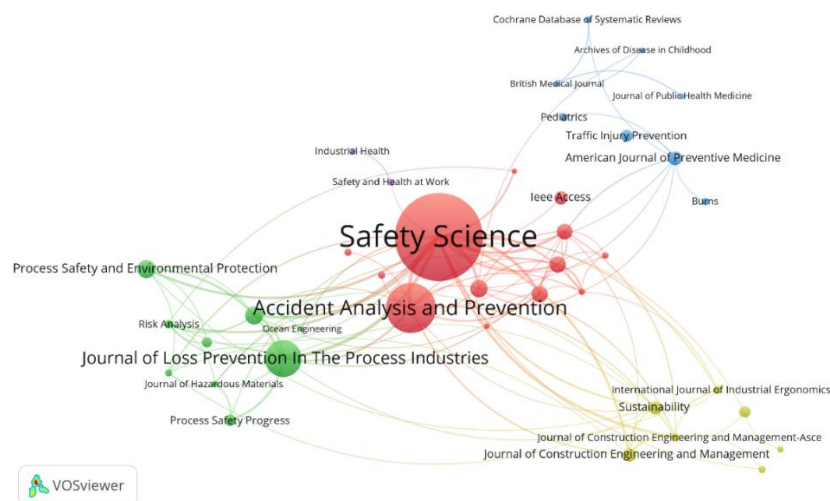
Figure 7. Co-operation of journals in accident prevention studies.

3.3. Research Knowledge Base

The knowledge base reflects the essence of a research field, to a certain extent. There are multiple free knowledge units in different papers, and when other literature is cited in the same paper, this represents a formal integration of multiple free units into a new knowledge base. As the citation network evolves, a knowledge base is formed. Therefore, the knowledge base of a field can be studied by conducting a co-citation analysis of literature and journals [42].

3.3.1. The Literature Co-Citation Analysis

The American scholar Henry Small put forward the concept of literature co-citation in 1973 [43]. Two papers form a co-citation relationship when two papers appear together in the reference catalog of the third citation literature. By generating a co-citation network in a specific research field, the professional structure and research ideas in this field can be obtained. Furthermore, high co-citation journals represent high-quality journals in this research field. The co-citation relationship of the literature reflects the relevance of the literature content, and the co-citation frequency of the literature is proportional to the correlation of the research content [44]. In this paper, VOSviewer is used to analyze the co-citation literature to understand the basic knowledge and core journals in the accident prevention studies. To form a co-citation literature network diagram with four clusters, 49 nodes were filtered (see Figure 8). The node size represents the frequency of co-citation, and the distance between the nodes is proportional to the relationship between the literature. From Figure 8, it can be concluded that the knowledge base in accident prevention studies during 1990–2021 contains four main categories.

System analysis and accident modeling (red clustering): system safety is particularly important to many industries. In a broad sense, it refers to the state or goal of sustainably ensuring accident prevention. Therefore, analyzing the system first and building appropriate models can explain the root causes of accidents and effectively prevent them. Rasmussen summarized the need to improve the safety research paradigm through interdisciplinary modeling for risk analysis and the integration of cornerstone theory and management research [45] (co-cited 50 times). Reason et al. proposed the need to distinguish between errors and violations that lead to accidents and to adopt different approaches to remedy them [46] (co-cited 50 times). Leveson put forward a new accident analysis model based on systems theory that provides a theoretical basis for introducing new and unique accident analysis, hazard analysis, and accident prevention strategies, including new safety design methods, risk assessment techniques, and methods for designing performance monitoring and safety indicators [47] (co-cited 36 times).
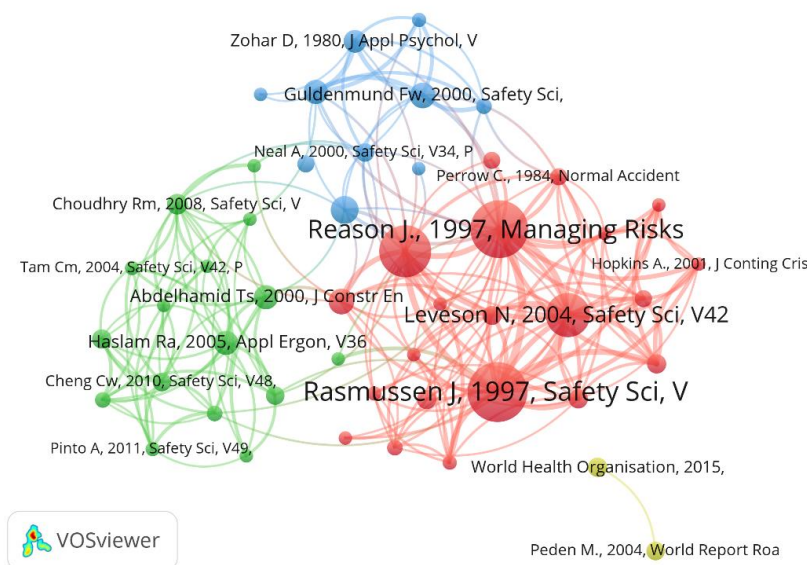

Figure 8. The co-citation literature network of accident prevention studies [45–58].

Construction accident analysis (green clustering): Abdelhamid et al. proposed an accident root causes tracing model (ARCTM), according to the characteristics of the construction industry, including three root causes of accidents and four causes of unsafe conditions [50] (co-cited 19 times). Through the investigation of 100 construction accidents, Haslam et al. used an ergonomic systems approach to model the causes of accidents, suggesting that the original management, design and cultural factors shaped the workplace environment in

ways that produced behaviors and conditions [51] (co-cited 19 times). Suraji et al. proposed a model for the construction industry that emphasizes the interaction of various factors in the cause-and-effect relationship, involving the influence of behaviors at various stages of project conception, design, and construction on the occurrence of accidents [59] (co-cited 14 times). Tam et al. focused on safety management in the process of building construction, and the main factors affecting construction safety in China included "poor safety awareness among senior management", "lack of training", "poor safety awareness ", " low investment ", and "carelessness" [53] (co-cited 11 times).

Road accident prevention (yellow clustering): *The World Report on Road Traffic Injury Prevention*, presented by Peden Margie et al. to the World Health Organization in 2004, aimed to raise awareness of road safety issues. It contributed to a shift in thinking about the nature of traffic accidents and recognized the importance of traffic accidents as a public health issue [54] (co-cited 15 times). Hughes et al. reviewed seven types of models, which can be effective in reducing road accident injuries. Models such as system theory, safety management systems, risk management approaches, and safety culture were not universally applied to road safety [60] (co-cited 16 times).

Safety culture and safety climate (blue clustering): Guldenmund distinguished safety culture and climate based on Schein's general framework of work on organizational culture, arguing that safety climate could be used as one of the safety indicators [56] (co-cited 20 times). Flin et al. assessed the safety climate in the UK workplace from a psychological perspective, suggesting that job stress was related to competence (co-cited 19 times) [61]. Mearns conducted a safety climate survey of 13 offshore oil and gas projects and found that proficiency of safety management is inversely proportional to the accident rate (co-cited 11 times) [62].

3.3.2. The Journal Co-Citation Analysis

The core journals in this research field can be identified through journal co-citation analysis, which is helpful in finding the most relevant and influential journals with a particular research topic [63]. Using VOSviewer for journal co-citation analysis, a journal co-citation network with four clusters was obtained (see Figure 9). The node size represents the frequency of co-citation, and the distance between the nodes is proportional to the relationship between the journals.
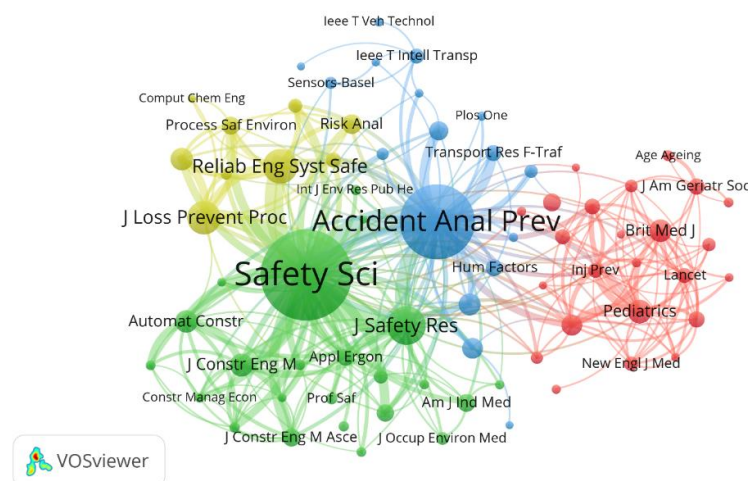

Figure 9. The journal co-citation network of accident prevention studies.

The 73 journals form four clusters in green, blue, red, and yellow, each representing a research direction, namely safety, accident prevention, public health, and engineering. The green clustering includes security journals, represented by *Safety Science* (co-cited 2156 times) and *Journal of Safety Research* (co-cited 577 times). The blue clustering involves journals of accident investigation and analysis, represented by *Accident Analysis and Pre-*

vention (co-cited 1597 times), *Ergonomics* (co-cited 242 times), and *Transportation Research Record* (co-cited 195 times). The red clustering includes medicine and public health journals, and is based on *Pediatrics* (co-cited 277 times), *British Medical Journal* (co-cited 252 times), *American Journal of Public Health* (co-cited 22 times), and *Public Health* (co-cited 22 times). The yellow clustering is for industrial engineering journals, which mainly include *Reliability Engineering & System Safety* (co-cited 492 times), *Journal of Loss Prevention in The Process Industries* (co-cited 467 times), and *Journal of Hazardous Materials* (co-cited 253 times). The journals with the highest co-citation in the four clusters are the core journals in accident prevention studies: *Safety Science*, *Accident Analysis and Prevention*, *Pediatrics*, and *Reliability Engineering & System Safety*.

3.3.3. The Co-Authorship Analysis

Scholars with a high number of publications and high citations tend to dominate concepts and methodological trends and play a key role in the development of this field. As many as 4563 relevant authors were obtained from the SCI and SSCI database. Table 6 shows the authors of the top 10 posts with their countries, institutions, and major research areas. Links represent active collaboration with others. The author with the highest posts with an average citation of 25.85 is Saleh from Georgia Inst Technol, USA, whose main research content is accident causation theory and system reliability analysis, and his collaboration with other authors is also the highest. China scholar Fu has the highest average citation, whose research on coal mining and the chemical industry has received high attention from other scholars. Jeong from Korea has published 7 related papers and ranks second, but his average citation is only 5.50, which is at the bottom of the list, indicating that his published articles are of lower thematic interest. More than half of the authors are from Europe and America, showing that the research in the field of accident prevention is more mature in Europe and the United States, and more attention is paid to the prevention and management of accidents.

Table 6. Top 10 authors in accident prevention, 1990–2021.

Rank	Author	Country	Institute	TP	ACI	Main Research Interests
1	Saleh	USA	Georgia Inst Technol	15	25.85	Accident causation theory System reliability analysis
2	Jeong	South Korea	Hansung Univ	11	5.50	Occupational health and safety
3	Kendrick	UK	Univ Nottingham	11	16.50	Family and child health
4	Khan	Canada	Mem Univ Newfoundland	8	25.71	Probabilistic fault tree analysis Risk assessment
5	Kim	South Korea	Hanyang Univ	8	19.86	New energy research
6	Liu	USA	Rutgers State Univ	8	11.86	Analysis of traffic and transportation accidents
7	Abbasi	India	Pondicherry Univ	7	1.50	ORA (Optimal risk analysis) Maximum reliability accident analysis
8	Favaro	USA	San Jose State Univ	7	20.71	Security monitoring Risk assessment
9	Fu	China	China Univ Min & Technol Beijing	7	29	Coal mine, chemical cccident research
10	Reniers	Belgium	Univ Antwerp	7	12.5	Safety management Safety assessment

Notes: TP: Total publications; ACI: Average Citations per item.

VOSviewer is used to analyze the data derived from WOS. After screening, the authors with more than three collaborations formed clusters and drew a co-authorship network (see

Figure 10). The node size represents the number of posts, and the width of the connection is proportional to the intensity of co-authorship.

Red clustering contains the largest number of authors. Seven authors in the clustering are from the United States, and most of them are scholars in the initial stage of accident prevention research. The research topic is accident prevention in children's family safety. In addition, Saleh and Jeong, the authors with the top two number of posts do not often cooperate with others.

It is obvious from the figure that in accident prevention studies, the intensity of co-operation between authors is low, the main research interests and co-operation objects of authors are relatively fixed and single, and the co-operation between authors is mostly based on institutions or regions.
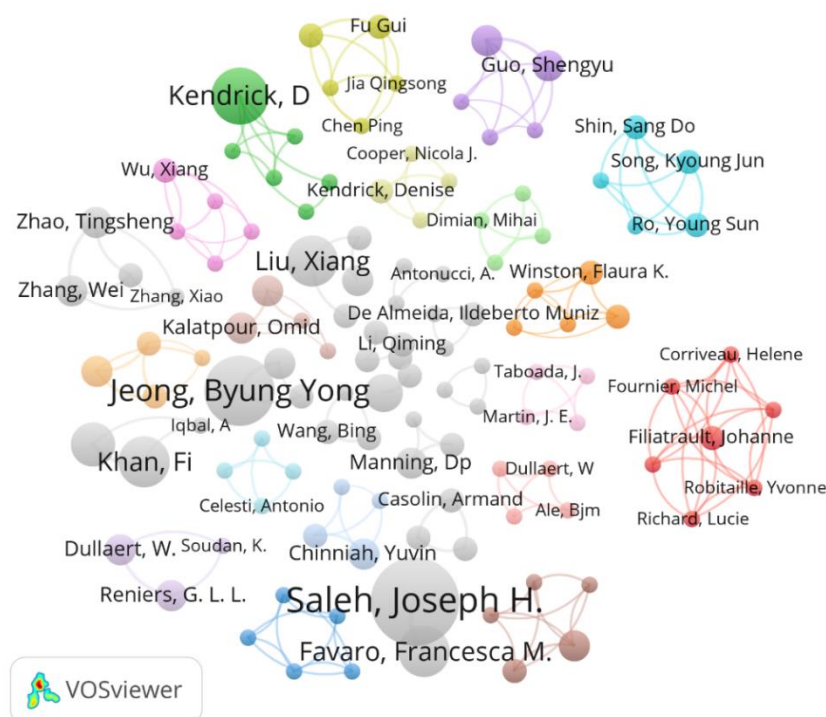

Figure 10. The co-authorship network of accident prevention studies.

3.4. Research Hotspots and Frontier Analysis

3.4.1. Keyword Co-Occurrence Analysis

As the most concise summary of the topic in an article, the changes in frequency and time of keywords can indicate the changes in research hotspots and methods. Therefore, co-occurrence analysis of keywords can be used to identify the developing research frontiers related to the field of knowledge. The obtained sample contains a total of 53,921 keywords. Keywords in the top 20 of occurrence frequency were taken to generate Table 7.

Having set the minimum occurrence frequency to five in VOSviewer, and manually screen the misspelled and repeated keywords, 285 valid keywords were extracted to obtain the keyword co-occurrence map (see Figure 11). Different nodes represent different keywords, and the more the number of abstracts and titles with the same two keywords, the closer the corresponding nodes are. A total of four clusters were formed, and one clustering represents a group of closely related nodes, indicating a specific aspect of the study. Figure 11 shows that red clustering and green clustering dominate.

Table 7. The top 20 keywords of accident prevention studies, 1990–2021.

Rank	Keywords	Occurrences	Total Link Strength	Rank	Keywords	Occurrences	Total Link Strength
1	accident prevention	489	1427	11	Attitudes	20	108
2	accidents	144	363	12	care	20	70
3	behavior	52	212	13	construction safety	20	69
4	accidental falls	44	209	14	aged	27	72
5	children	63	127	15	balance	14	77
6	climate	32	180	16	burns	14	47
7	accident analysis	28	80	17	classification	14	58
8	culture	27	135	18	Bayesian network	12	47
9	construction	25	123	19	causation	12	48
10	crashes	21	82	20	construction industry	12	41
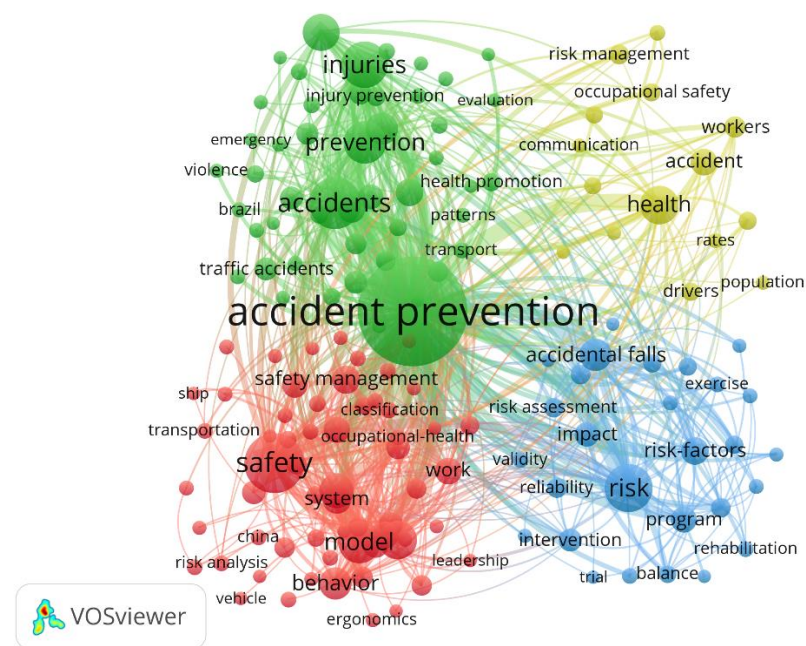
Figure 11. Keywords co-occurrence network of accident prevention studies.

Family accident prevention (green clustering): The most frequent keyword is "accident prevention", which is the center of all keywords with 532 nodes covering all color clusters. In addition, the high-frequency keywords such as "injury" and "mortality" show that the main purpose of accident prevention is to reduce the casualty rate of accidents. Kambas et al. found that accidents in childhood are mainly "falls at play", so the organized development of motor coordination and specific motor skills can be effective in preventing accidents [64]. Ma summarized the temporal and spatial distribution of traffic accidents, pointing out that the probability of accidents in tunnels was lower than in open roadways, but the severity of injuries in accidents that have occurred in tunnels was significantly higher than in open roadways [65].

Model-based research (red clustering): "Safety", "model", and "management" are the main foci. "Safety" is the purpose of research, "model" is the theory and method of research, and "management" is the means to achieve safety. Favaro and Saleh developed a hazard time contingency diagram for improved risk assessment and accident prevention, with predictive information that could alert operators to intervene in hazardous situations before they become unrecoverable [66]. Uzun and Cebi used a fuzzy Kano model approach to classify measures to protect and prevent occupational health problems, and analyzed occupational health and safety measures from a new point of view [67].

Systematic analysis and accident prediction (blue clustering): This mainly includes "risk", "accidental falls", "program", and "reliability". This clustering predicts the occur-

rence and consequences of accidents by analyzing the causes of accidents and the reliability of the system. Kaskutas et al. developed the St. Louis Assessment, which is a reliable tool for measuring fall safety risks at construction sites [68]. Sonnemans et al. proposed a seven-stage detection method to detect potential conditions from the working condition of the previous stage, leading to accidents in the later stage,, which can improve system safety [69]. Cao et al. established a multi-level risk control technology system for coal mines, to clarify the contents of risk management, and also developed a "multi-level risk control system for coal mines", which helps to carry out multi-level risk control in coal mines in a scientific and standardized way [70].

Occupational safety and public health (yellow cluster): There are fewer keywords in yellow clustering. Keywords that appear more frequently are "health", "workers" and "occupational safety". This clustering is related to occupational safety and health training for employees [71,72], interventions for risk factors for illness and injury in the workplace [73,74], and inspection and management of the public health system at the national level [75].

3.4.2. High-Cited Literature Analysis

The influence and quality of the publication can be obtained by counting the number of times the literature is cited by other literature [19]. The analysis of highly cited literature allows us to explore the core elements in a field of research. To measure the most influential literature in the f accident prevention studies, the first 15 papers with the largest number of related citations were selected, as shown in Table 8. Table 8 lists the title, journal, type of literature, author, publish year, sum of the times cited (STC), institutions number (IN), and countries number (CN), and literature co-authored by more than three authors shows only the first author.

A new accident model for engineering safer systems by Leveson published in the journal *Safety Science,* which presented a new accident model, was cited the most (1029 citations). The use of this model provided a theoretical basis for introducing unique new accident analysis, hazard analysis, and prevention strategies (including new safety design methods), risk assessment techniques, and design performance monitoring and safety metrics [47]. The second most cited is a review by Shults et al. in *American Journal of Preventive Medicine*: *Reviews of evidence regarding interventions to reduce alcohol-impaired driving* [76] (cited 415 times). The article, based on a study of consultants and experts in the field in the context of DUI crashes, concluded that five interventions—setting a minimum drinking age, lowering blood alcohol concentration limits, establishing sobriety checkpoints, increasing alcohol beverage control, and training alcohol beverage servers—were effective in reducing the probability of alcohol-impaired crashes, and provided more information on the applicability, other effects, and barriers to implementation of these interventions. Lisbona's paper, *A review of hazards associated with primary lithium and lithium-ion batteries* [77] (340 citations), reviewed hazards related to primary lithium and lithium-ion batteries, examined the safety mechanisms for preventing accidents and limiting the consequences of accidents. Furthermore, he tested compliance with battery safety regulations and standards, and concluded that the potential severity of accidents during storage, transportation, and recycling of used batteries may be much higher than that of end-use applications. In conclusion, Lisbona proposed recommendations for establishing a lithium battery database to provide effective information for accident prevention.

Table 8. The top 15 papers with the most citations, 1902–2021.

Rank	Title	Journal	Type	Authors	Year	STC	IN	CN
1	A new accident model for engineering safer systems [47]	Safety Science	Article	Leveson	2004	990	1	1
2	Reviews of evidence regarding interventions to reduce alcohol-impaired driving [76]	American Journal of Preventive Medicine	Review	Shults et al.	2001	441	4	1
3	A review of hazards associated with primary lithium and lithium-ion batteries [77]	Process Safety and Environmental Protection	Article	Lisbona	2011	323	1	1
4	Effects of exercise programs on falls and mobility in frail and pre-frail older adults: a multicenter randomized controlled trial [78]	Archives of Physical Medicine and Rehabilitation	Article	Faber et al.	2006	299	2	1
5	Cerebral palsy [79]	Lancet	Article	Colver et al.	2014	239	4	1
6	The epidemiology of fractures in children [80]	Injury-International Journal of The Care of The Injured	Article	Rennie et al.	2007	227	1	1
7	Development of causal model of construction accident causation [59]	Journal of Construction Engineering and Management-Asce	Article	Suraji et al.	2001	204	2	2
8	A cross-validation of safety climate scale using confirmatory factor analytic approach [81]	Journal of Safety Research	Article	Seo, et al.	2004	182	1	1
9	Risky and aggressive driving in young adults: Personality matters [82]	Accident Analysis and Prevention	Article	Constantinou et al.	2011	178	1	1
10	Oil spill problems and sustainable response strategies through new technologies [83]	Environmental Science-Processes & Impacts	Review	Ivshina, IB et al.	2015	173	6	4
11	Systems model of construction accident causation [84]	Journal of Construction Engineering and Management	Article	Mitropoulos et al.	2005	173	1	1
12	Behavior change versus culture change: Divergent approaches to managing workplace safety [9]	Safety Science	Article	DeJoy	2005	171	1	1
13	Associations between risk perception and safety [85]	Safety Science	Article	Rundmo	1996	169	1	1
14	Influence of long-term orotracheal or nasotracheal intubation on nosocomial maxillary sinusitis and pneumonia-results of a prospective, randomized, clinical-trial, clinical-trial [86]	Critical Care Medicine	Article	Holzapfel et al.	1993	169	3	1
15	Sleep problems and work injuries: A systematic review and meta-analysis [87]	Sleep Medicine Reviews	Review	Uehli et al.	2014	165	3	2

Notes: STC: sum of the times cited; IN: institute numbers; CN: country numbers.

The cited literature covers a wide range of research topics, including medicine, engineering, transportation, environment, etc. The common denominator is that accident prevention research is conducted from the perspective of improving human safety, and human behavior is the main subject of accident prevention research. Of the 15 articles, only three were completed through international co-operation, and the rest were completed independently or cooperatively by domestic institutions, which shows that the co-operation among scholars in this field is mainly regional, reflecting inter-agency co-operation.

3.4.3. Combing Evolution Path

The citation data and graphical analysis of the literature can quickly present the relationship between different literature in a certain field, analyze the evolution process of related fields, locate the important literature in the field, and obtain the latest high-value literature, etc. Combined with the citation and release time of the article, the evolution path and research hotspots in the field of accident prevention can be obtained. The top 50 cited papers were selected and the literature citation data and graphs were constructed by HistCite auxiliary software (see Figure 12).
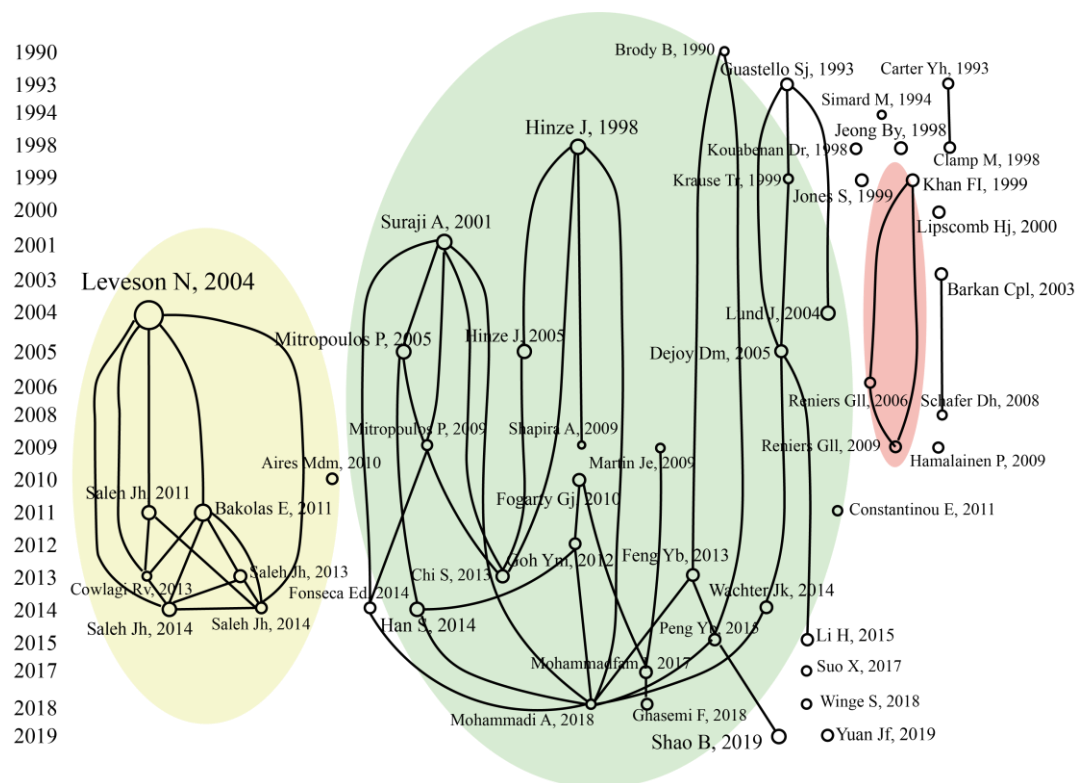

Figure 12. Citation network map of highly cited articles [9,18,36,47,59,82,84,88–130].

As shown in Figure 12, the main evolution paths in accident prevention are divided into three blocks. In the yellow path, the starting point is the new accident model of safety systems engineering proposed by Leveson in 2004 [47] and applied to the safety analysis of mining systems [88]. Based on this, a series of new accident analyses and system safety theories were put forward. The characteristic of the green path is from decentralized to centralized, ranging from the cost theory of industrial accident prevention to the relationship between safety investment and safety benefit of enterprises, on the one hand [50,83,84], and on the other, combining ergonomics to shift the focus of accident prevention to the management of various unsafe behaviors in operations [36,96,98,100], and conduct accident analysis and classification of accident causes [97,99,101,105]. In 2009, the use of Bayesian networks and system dynamics was highlighted to incorporate psychological

factors such as safety culture and work stress into the analysis of occupational safety and accidents [18,102,104,111,113]. Mohammadi et al. comprehensively reviewed the above papers and established a hierarchy of interacting safety factors [112]. The red path plots the risk assessment, major event decision support and safety management in different articles relating to the chemical industry [122,126,127]. The remaining scattered points are not linked into a complete pathway, with studies include earlier childhood accident prevention [123,124], governmental accident prevention policies [89], major accident investigation and reporting [121], rail transportation risk [128,129] and the 24Model accident causation model [115] and the concept of Prevention through Design (PTD) [116].

3.4.4. Research Frontier Identification

An accident prevention keyword time-series diagram from 2000 to 2021 was generated through Timeline View analysis of keywords by CiteSpace (see Figure 13). In the keyword sequence diagram, the abscissa represents the time, every node represents a keyword, and the connection between the nodes represents the co-occurrence relationship between the keywords. The size of the node is proportional to the number of keywords, and the darker the color of the node is, the higher the burst is. The node centrality of the purple outline is greater than 0.1, and then this keyword is a hub connecting other keywords.

There are six timelines in Figure 13, representing six research themes: accident analysis, accident prevention, fall accidents, epidemiology, building construction, and Bayesian networks. The keywords with the top three centrality are "injury" (0.45), "health" (0.137), and "epidemiology" (0.26). Research on accident prevention from 2000–2005 focused on "injury", "health", and "alcohol drinking". From 2006 to 2015, the research direction was expanded, and the research focus was on "model", "analysis", and "analysis". This research focus was used to analyze the factors affecting accidents and to prevent accidents from the root through the management of personnel and the improvement of systems by mathematical models. The research hotspots from 2016 to 2021 are "accident tree", "system analysis", "Bayesian network", and "simulation", devoted to establishing safety science accident analysis models, and fully using computer technology, system science and engineering principles as a means of accident analysis and prevention measures.
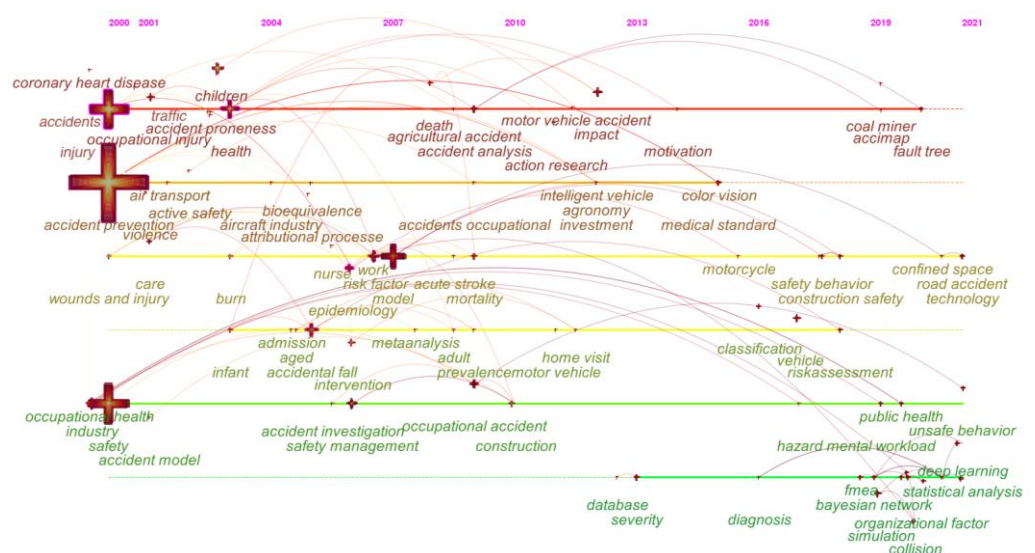

Figure 13. The keywords timeline view of accident prevention studies.

Through the Burst Detection program in the software CiteSpace, the 10 keywords with the greatest mutation intensity from 2000 to 2021 can be obtained, representing the research hotspots and their developmental changes in the past two decades (see Table 9). "System" (8.92) has the highest mutation intensity, which is the main research subject of accident

prevention. The second is "risk management" (7.47), which is the main means of accident prevention. "Prevention" (6.13) is the ultimate goal of the study. The longest duration of the "intervention" mutation is the one in which scholars pay special attention to the feasibility and effectiveness of various interventions for accident prevention. "System", "safety management", "simulation", and "Bayesian network" are currently being studied at the forefront of research in the field of accident prevention at present, analyzing the system and improving safety management measures through simulation through Bayesian network and other computer technologies to achieve the purpose of improving safety efficiency.

Table 9. Top 10 keywords with the strongest bursts.

Keywords	Year	Strength	Begin	End	2000–2021
prevention	2000	6.13	2003	2009	
intervention	2000	5.32	2006	2015	
risk factor	2000	4.12	2009	2010	
fatality	2000	5.11	2015	2017	
risk management	2000	7.47	2016	2019	
occupational injury	2000	4.98	2016	2018	
system	2000	8.92	2018	2021	
safety management	2000	5.64	2019	2021	
simulation	2000	4.97	2019	2021	
Bayesian network	2000	3.72	2019	2021	

4. Conclusions

This paper used the information visualization software, CiteSpace and VOSviewer to make a bibliometric analysis of the relevant literature on accident prevention research in the core databases SCIE and SSCI of Web of Science from 1990 to 2021, which focuses on the temporal-spatial distribution, high-cited literature, co-authorship, research knowledge base, research path, research hotspots, and frontier. By drawing the network of the accident prevention research literature, we identified the four types of the knowledge base in this field, the research hotspots in each period, and sorted out the core evolution path of the topic, before identifying the current research frontiers in the field of accident prevention. The following three main conclusions are drawn.

(1) The development of the accident prevention field has been divided into four phases: the exploratory stage (1902–1965), the theory formation stage (1966–1990), the steady development stage (1990–2011) and the rapid development stage (2011–2021). Before 2015, the USA had the highest number of publications in accident prevention studies and was in the leading position in the world. China followed closely, -surpassing the USA in 2015. However, the USA still leads the world in terms of the depth and breadth of research. The four countries with the most publications, the USA, China, the UK, and Australia, also have the most frequent collaboration. The distribution of disciplines reflects the fact that accident prevention is a multidisciplinary research field involving engineering, management, medicine, economics, chemistry, social sciences, computer science, and other disciplines. The highest quality publications were published by Georgia Inst Technol. *Safety Science*, *Accident Analysis and Prevention*, and *Journal of Loss Prevention in The Process Industries* are the main carriers of literature in this research area.

(2) The knowledge base of in the field in accident prevention studies is system analysis and accident modeling, building construction accident analysis, road accident prevention, and safety culture and safety climate. In accident prevention studies, scholars usually choose to investigate and count one type of accident, establish and use reasonable models to analyze the causes, influencing factors, and consequences of such accidents, get conclusions and propose generally applicable preventive measures, creating a safe atmosphere to achieve the ultimate goal of accident prevention and safety. The co-citation literature can be divided into four categories: safety, accident prevention, public health, and engineering.

The journals with the highest co-citations in each category are extracted as the core journals in this field, including *Safety Science*, *Accident Analysis and Prevention*, *Pediatrics*, and *Reliability Engineering & System Safety*.

(3) At present, four hot spots have been formed in accident prevention research: daily accident prevention, model-based research, system analysis and accident prediction, and occupational safety and public health research. The basic theories and research systems in accident prevention studies have been roughly established, with many research directions and a wide range of frontier branches. The evolution of accident prevention research themes can be simplified as research scope: chemical field–multi-industry intersection; research object: human system; research means: questionnaire survey–model building simulation. Safety management, public safety, Bayesian networks, and simulation are the frontiers of accident prevention research.

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