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Analysis of Frontier Knowledge Graph for Safety Culture Research

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Abstract:

To explore the current leading institutions, scientists, and their research interests and to predict the future hot topics of safety culture, CiteSpace5.7.R1 was used to analyze the 17,910 articles collected from the Web of Science (WoS) after searching "safety culture" for literature published between 1985 to 2021. The number of publications has increased year over year. The USA, Peoples Republic of China, and England were the top countries producing literature in the safety culture research field, and J Bryan Sexton, Peter J Pronovost, and Cordula Wagner were the most productive authors with high outputs, but these authors lack communication and collaborations with each other. Moreover, current studies focus primarily on patient safety, in vitro, food safety, efficacy, and sediment. It is speculated that future studies could concentrate on food safety culture, psychological safety, adverse events, and patient safety culture. This study provides a new approach to visualize relevant data over the past three decades to synthesize the scientific research findings on safety culture.

Keywords*: Safety culture; CiteSpace; Bibliometrics; Visualization analysis; Emerging trends.*

I. INTRODUCTION

In 1983, the explosion of the Chernobyl nuclear power plant in the former Soviet Union was a worldwide catastrophe. The final report on the accident argued that it was caused by unsafe human behaviors (human error). In the same year, in the INSAG-1 summary report [1], the International Nuclear Safety Advisory Group of the International Atomic Energy Agency (IAEA) introduced the concept of safety culture. It is generally believed that safety culture originates from a safe atmosphere. In 1991, the IAEA held the International Nuclear Energy Safety Conference—Future Strategy in Vienna. Safety culture was defined for the first time in the summary report (INSAG-4) entitled Safety Culture [2]. It is defined as the sum of the various characteristics and attitudes that exist in units and individuals and is a knowledge system that is reused to construct and understand the safety of normative behaviors. As society has developed, safety culture has drawn many scholars' attention and has been widely used in various aspects such as mines, transportation, nuclear safety, hospitals, and schools [3–8]. Despite its recognition and

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application in various industries, a comprehensive, systematic, and clear understanding of safety culture is still an issue in safety culture research [9].

A map of scientific knowledge is an effective tool to reveal the development of science and has played an important role in describing the overall picture of certain subjects. This concept has been widely used to predict near-future research. The scientific knowledge map approach is based on scientific literature data and computer visualization technology, which are combined with the basic mechanism of bibliometrics to show scientific research in the form of maps [10]. In this context, bibliometric theory and document map tools are used here to research the cooperation network, co-occurrence, and co-citation of safety culture. The aim is to fully demonstrate the basic situations and develop the information for safety culture research to provide context.

II. DATA ACQUISITION AND METHODS

2.1 Bibliometric database

Bibliometric data retrieved from the Web of Science (WoS) was used in this study. The WoS, Scopus, and Google Scholar are the three main online data resources for bibliometric analyses. The WoS is one of the best-known and most widely used library resources with more than 7,000 subscribers [11], which is twice its closest competitor Scopus。 Google Scholar is a free online search engine that provides citation information and covers a wider range of citation sources that include unpublished documents, blog posts, and web pages. However, Google Scholar was not used in this study. Although it does not discriminate between academic and nonacademic citations—which may result in bias because citations from nonacademic works and academic journal articles might not have equal scholarly value [12]—it does not offer co-citation information, which is of vital importance in the current study CiteSpace was developed by Dr. Chaomei Chen [13] and is a Java-based scientific visualization software package. It can analyze and visualize co-citation networks and perform various functions to facilitate the understanding and interpretation of network patterns. This includes identifying major topic areas, finding hotspots, and automatically labeling clusters with terms from the selected literature [14]. In this study, data were collected from the Web of Science Core Collection (WoSCC), which includes SCIE(Science Citation Index Expanded)，SSCI(Social Sciences Citation Index),IC（ Index Chemicus）, CCR(Current Chemical Reactions).The search formula was: TS = Topic: “Safety Culture,” the search period was set as “All years (from 1985 to 2021, data as of March 2021),” the document type was set as “Article,” and the publication language was set as “English.” A total of 17,190 references were retrieved under these conditions. The search date was March 1, 2021. All articles were downloaded and stored as .txt format files and included titles, keywords, authors, abstracts, descriptors, and identifiers.

2.2 Analysis tool

The contributing authors, countries, and journals are first mapped using CiteSpace to identify and visualize the major factors that contribute to the evolution of the knowledge map. Important topics and

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frontline research in safety culture are also identified based on the frequency of popular keywords used in journal articles. When viewing the maps, a node represents one item such as a keyword, journal, or reference. The links describe the co-citation or co-occurrence between nodes. Each node is depicted with a series of tree rings of different colors: blue indicates the oldest and orange indicates the newest.

CiteSpace also makes it easier to identify pivotal points by recognizing the nodes with a high betweenness centrality [15]. Pivotal points are highlighted with the purple ring to stand out in a visualized network. The betweenness centrality is defined as

$$Centrality(nodej) = \sum_{i \neq j \neq k} \frac{\rho_{jk}\ (i)}{\rho_{jk}} \quad (1)$$

where ρjk represents the number of shortest paths between nodes j and k, and ρjk (i) is the number of paths that pass through node i. At the document level, the importance of each document in a co-citing network can be partially evaluated using the betweenness centrality indicator [16]. In general, The Q value and silhouette (S) are used to evaluate the scientific usability in the visualization knowledge maps. When Q is higher than 0.3, there is a significant network cluster structure. When S is above 0.5, the clustering results have a high reliability.

2.3 Publication Time Distribution

Annual literature analysis is conducive to the time distributions and the degree of attention to safety culture research. The statistical results are shown in Figure 1. Relatively few studies were published from 1985 to 1995, and only 129 articles on safety culture processing were published in 1996. However, since 2013, more than 1,000 safety culture-related documents have been published annually, and more than 1,500 articles were published in 2018. This trend shows that research on safety culture is becoming increasingly concentrated.

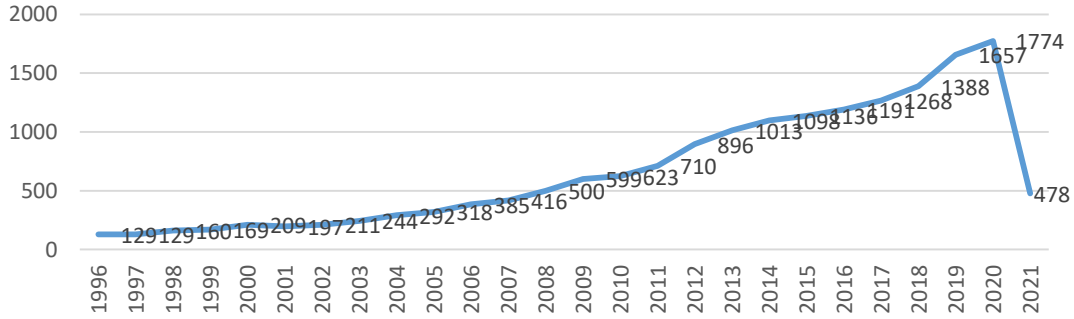

Figure 1: Annual published papers on the topic of safety culture.

III. NETWORK ANALYSIS OF SCIENTIFIC RESEARCH COOPERATION

It is widely acknowledged that science and technology develop and change at a quick pace. A single scientist cannot obtain all research resources and pay for expensive experiments; thus, cooperation is a good way to solve complex scientific research problems. CiteSpace can provide three levels of scientific cooperation for network analysis, including micro-scholar cooperation (co-Author), meso-level institutional cooperation (co-institution), and macro-country or regional cooperation (co-country/territory).

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The size of nodes in the cooperative network graph represents the number of papers published by authors, institutions, and countries/regions.

3.1 Author co-operation analysis

CiteSpace allows drawing a network of core authors and their cooperation. In the maps, the size of the nodes represents the number of papers that the authors published, while the links between nodes show the level of cooperation among authors. The parameters were set as follows: the time slice is from 1996 to 2021 with 1 year per slice, the node type is set to author, and the other settings are set as default. Figure 2 shows the co-author network with 1,238 nodes and 1,275 lines.

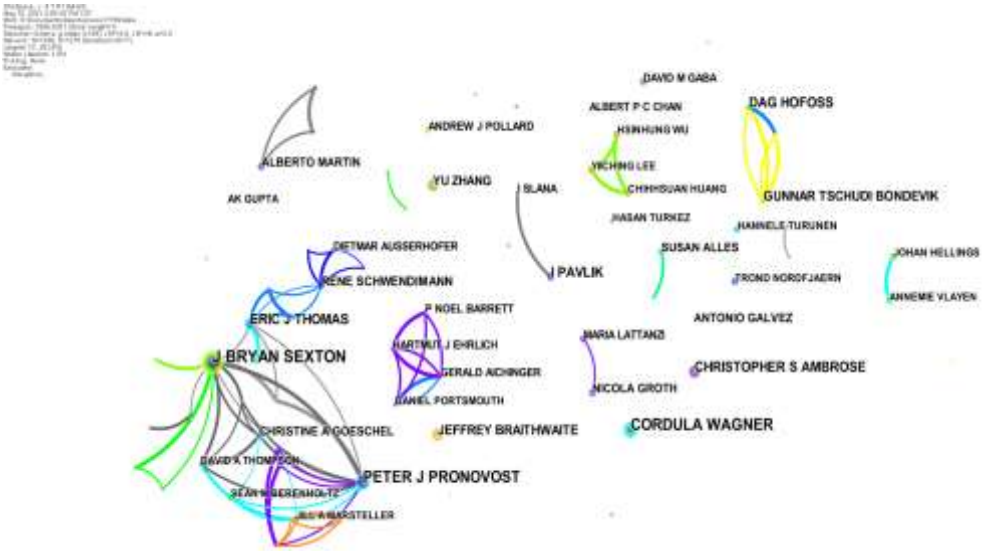

Figure 2: Cooperation network of productive authors.

In Figure 2, the nodes of J Bryan Sexton and Peter J Pronovost are larger, indicating that their publications are greater than that of their counterparts. Cordula Wagner, with 20 papers, is also among the key authors. For cooperation, Figure 2 and Table 2 indicate that the more productive authors tend to work in small cooperate groups while the less productive authors usually lack communications and collaborations with each other.

TABLE 1. List of the number of authors' publications.

Count	Year	Author
24	2006	J Bryan Sexton
21	2006	Peter J Pronovost
20	2010	Cordula Wagner
14	2006	Ivo Pavlik
14	2010	Christopher S Ambrose
13	2006	Eric J Thomas
11	2008	Dag Hofoss

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11	2014	Gunnar Tschudi Bondevik
10	2013	Rene Schwendimann
10	2015	Yu Zhang

In the author's collaborative group, J Bryan Sexton published a total of 24 articles. The publication "Creating high reliability in health care organizations" was cited 258 times; "Teamwork in the operating room-Frontline perspectives among hospitals and operating room personnel" was cited 187 times; and "Perceptions of safety culture vary across the intensive care units of a single institution" was cited 165 times. The number of publications per year for J Bryan Sexton is given in Figure 3.

Figure 3: Plot of the literature published by J Bryan Sexton over time.

In Figure 4, Peter J Pronovost published 21 articles, among which the top 3 articles were "Explaining Michigan: Developing an Ex Post Theory of a Quality Improvement Program," which was cited 381 times, "Creating high reliability in health care organizations" was quoted 258 times, "Teamwork in the operating room-Frontline perspectives among hospitals and operating room personnel" was cited 187 times.

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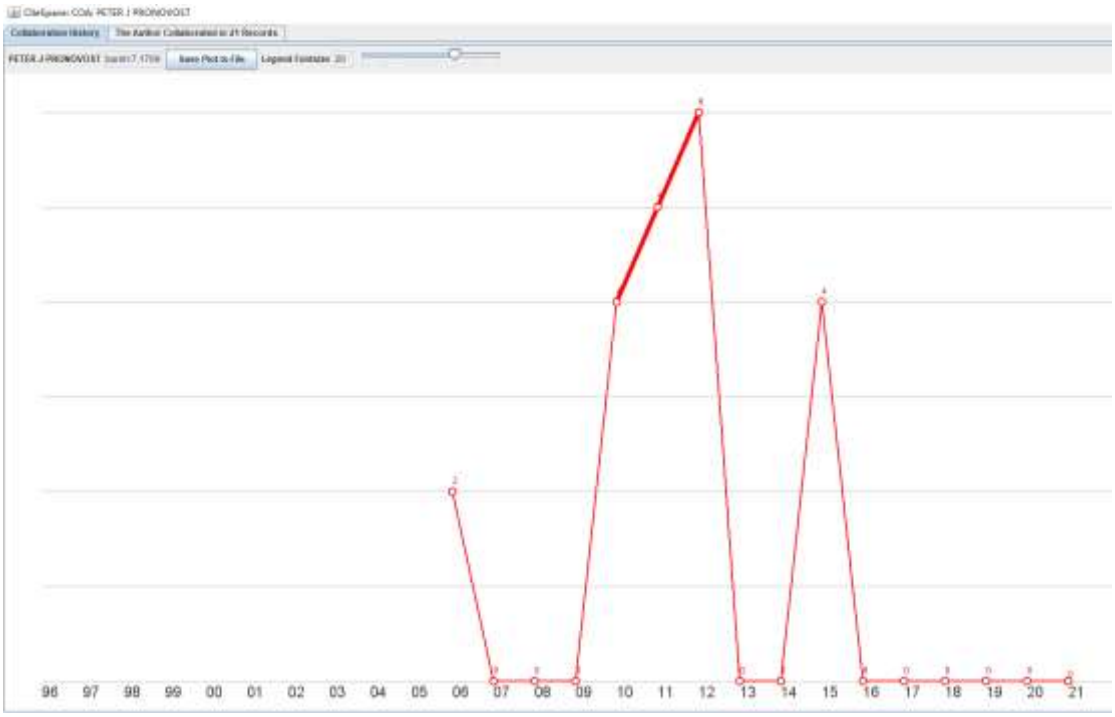

Figure 4: Plot of the literature published by Peter J Pronovost.

Among the other author collaboration groups, Cordula Wagner's "Deepening our understanding of quality improvement in Europe (DUQuE): overview of a study of hospital quality management in seven countries" was cited 54 times; and "Investigating organizational quality improvement systems, patient empowerment, organizational culture, professional involvement and the quality of care in European hospitals: the 'Deepening our Understanding of Quality Improvement in Europe (DUQuE)'" project was cited 43 times. Moreover, I Pavlik, Christopher S Ambrose, Dag Hofoss, and Gunnar Tschudi Bondevik also formed their own cooperation networks.

3.2 Institution co-operation analysis

The coordination of research institutions is a widespread form of scientific research cooperation. This can achieve complementary strengths and helps overcome major research topics. This analysis uses CiteSpace to consider research collaborations and generate a cooperative network map for safety culture research institutions. The map is obtained by selecting the institution nodes and running CiteSpace. There are 824 scientific research institutions with a network density of 0.0024, which is a relatively loose network structure. Most institutions are isolated, indicating that the frequency of cooperation between them is low. Further analysis of the cooperative community of research institutions reveals that a stable cooperation community in safety culture has not yet been formed. The results indicate that Harvard University, Johns Hopkins University, University Michigan had more publications at 194, 181, and 147, respectively (see Table 2). None of the nodes are considered central, which confirms the previous conclusions that institutional cooperation is weak in this area.

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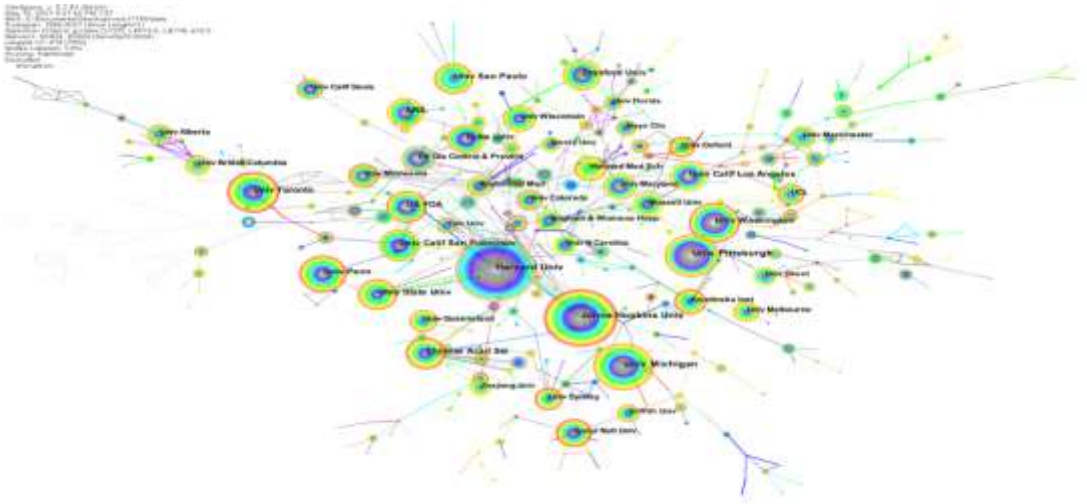

Figure 5: Cooperation network of productive institutions.

The node information was analyzed statistically through the operational results based on the analysis of the cooperation map of safety culture research institutions. The top 10 institutions are listed based on their frequency, as shown in Table 2.

TABLE 2. Top 10 most productive institutions.

Rank	Count	Centrality	Year	Institution
1	194	0.21	1998	Harvard University
2	181	0.13	1998	Johns Hopkins University
3	147	0.04	2002	University of Michigan
4	141	0.04	1998	University of Pittsburgh
5	128	0.14	2000	University of Toronto
6	123	0.14	1998	University of Washington
7	121	0.03	1998	University of Penn
8	106	0.01	1998	University of California San Francisco
9	104	0.05	1998	US FDA
10	102	0.04	1999	Ohio State University
10	102	0.09	2002	Chinese Academy of Science

3.3 Countries co-operation analysis

A network map of national cooperation in safety culture research is drawn by selecting the country node and running CiteSpace again, as seen in Figure 6.

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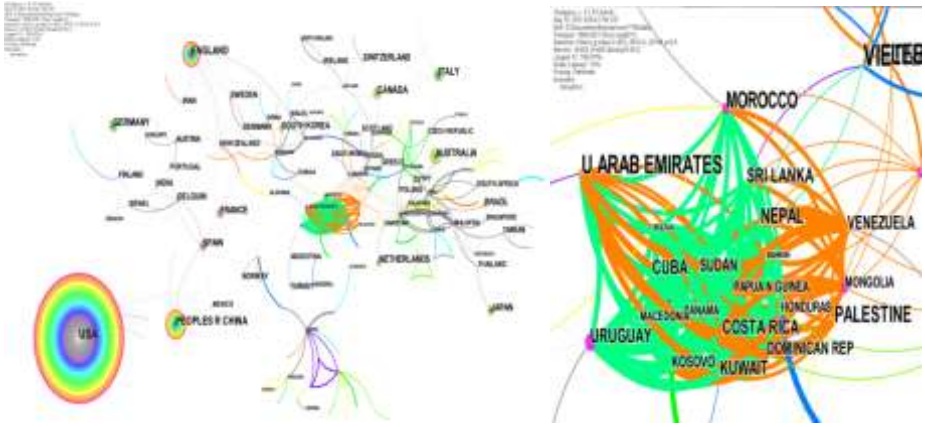

(a) (b)

Figure 6: Network map of safety culture research from various countries.

It is seen from Figure 6a that the nodes for the USA, Peoples Republic of China, England, Australia, and Germany have published the most literature through cooperation. However, there are few links between these countries, indicating highly productive countries do not collaborate with others. Most co-professors cooperate with domestic institutions. Although the nodes for the United Arab Emirates, Morocco, Palestine, Uruguay, Kuwait, and other countries are small, the cooperation between them is relatively high, as shown in the right panel of Figure 6(b). This close cooperation complements each other's strengths so they can learn from each other and the research on national security culture can develop rapidly to narrow the gap with other countries. From the statistical analysis of their nodes, the top 10 countries or regions with the highest frequency are listed based on frequency, as shown in Table 3.

TABLE 3. Top 10 countries ranked by the number of publications on safety culture research.

Count	Centrality	Year	Country
5954	0.26	1996	USA
1558	0.02	1998	Peoples Republic of China
1306	0.23	1996	England
912	0.04	1996	Australia
883	0.02	1996	Germany
847	0.06	1996	Italy
824	0.06	1996	Canada
717	0	1996	Japan
662	0.21	1996	France
612	0.2	1996	Spain

IV. DOCUMENT CO-OCCURRENCE ANALYSIS

The basic principle of the co-occurrence analysis is to count the number of times a group of words appears in the same set of documents as a measure of their relationship.

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4.1 Category co-occurrence analysis

The co-occurrence analysis of the disciplines creates a network of relationships that reveals the inter-disciplinary connections in the field of safety culture. CiteSpace is run and the category node is selected to obtain the co-occurrence map of the disciplines for safety culture research, as shown in Figure 7.

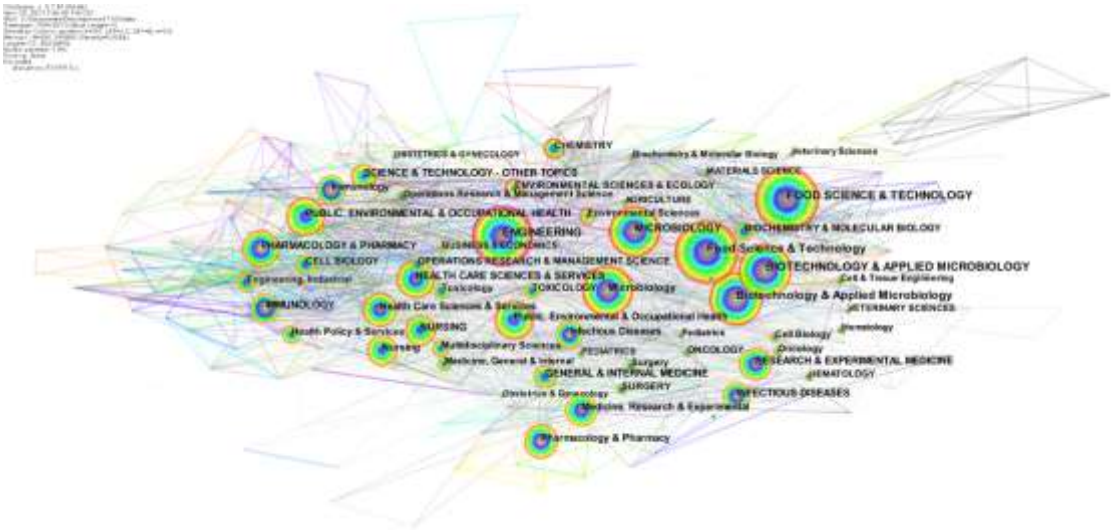

Figure 7: Category cooccurrence network for safety culture.

The co-occurrence diagram of safety culture disciplines has 366 nodes, indicating that 366 disciplines in safety culture research intersect and permeate each other. The 839 lines represent the connections between disciplines, suggesting that the fields involved in safety culture research are complex. Safety culture research mainly includes Food Science & Technology, Engineering, Biotechnology & Applied , Microbiology, Public, Safety and Environmental & Occupational Health. Among them, the intermediary centrality of Physics, Geosciences, and Biophysics is relatively high, indicating that safety culture has important research value and high relevance in these disciplines.

4.2 Keyword co-occurrence analysis

Important research foci are scientific issues that scholars consider through publications on different topics that are inherently related. Keywords are regarded as the soul of an article, and a keyword co-word analysis is used to detect research topics and analyze research frontier transitions for a given knowledge domain [17]. High-frequency keywords reflect the hot topics and core issues in the research field. CiteSpace has a keyword co-occurrence function to identify hot topics in the literature for the field of safety culture research. The node type is set as the keyword and the pruning method is selected as the pathfinder slice for the network+pruning merged network. Finally, 1,058 nodes with 5,721 lines were included to generate the network shown in Figure 8.

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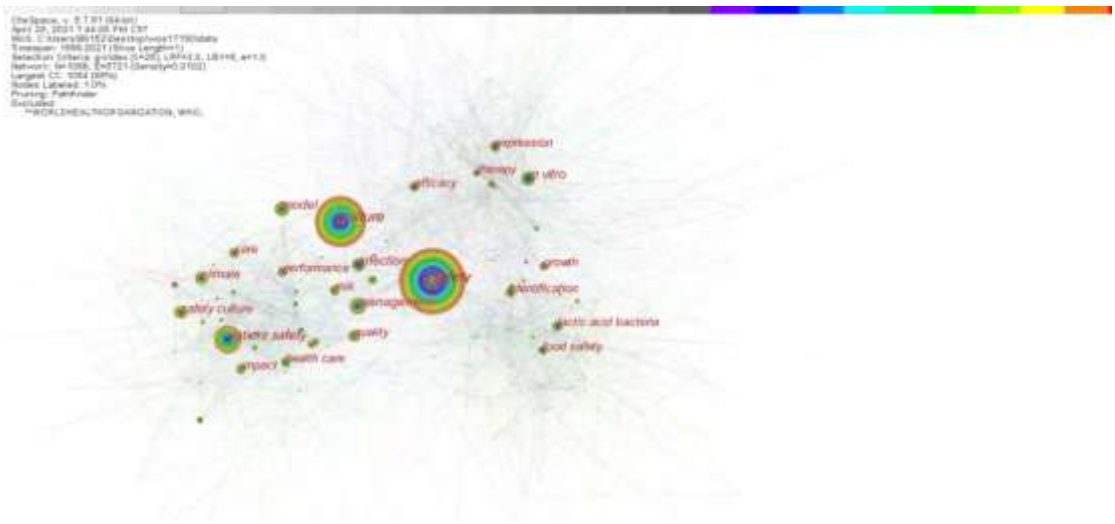

Figure 8: Keyword cooccurrence network of safety culture.

In the visualization analysis, the centrality of a keyword is an important indicator of a node's significance. Nodes with a centrality of more than 0.1 are called critical nodes. A higher centrality indicates the keywords are more important. In Figure 8, the largest node of "safety" is in the right-center of the image, which represents the highest frequency of usage. In addition, "culture," "patient safety," "infection," and "management" also received consistent attention.

TABLE 4. Top15 keywords of safety culture.

Count	Centrality	Year	Keyword
2599	0.01	1996	safety
2109	0.04	1996	culture
1152	0.01	2001	patient safety
786	0.02	1996	infection
768	0.02	1999	management
767	0.02	1997	in vitro
717	0.02	1998	model
654	0.02	1996	expression
643	0.01	1996	efficacy
632	0.00	1998	safety culture
625	0.02	2002	quality
606	0.01	2000	climate
605	0.02	1996	identification
600	0.02	1996	lactic acid bacteria
590	0.01	1996	therapy

The main idea of cluster analysis is to collect all the contexts of the words from the literature dataset and to derive relevant clusters that represent important research themes. Therefore, this study uses keyword clustering from the co-occurrence analysis to identify prominent thematic groupings and research patterns in safety culture. Each cluster has its own named label, which is calculated by extracting the

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cluster name from the title. A larger cluster size as generated from CiteSpace and the more members it contains produces a smaller number. The clustering analysis of the keywords and the selection of LLR clustering attains a total of 8 labels. The associated clustering is shown in Figure 9.

The variable of Q is an evaluation index for the network modularity. When Q is greater than 0.3, the network structure is significant. The Silhouette value (Silhouette) is an index to measure the homogeneity of the network [18]. The associated class results are considered reasonable. In this study, Q=0.5421 and Silhouette=0.8048, which indicates the themes of the nodes in the clustering have a strong correlation, while the clustering results have a high reliability and are of reference value.

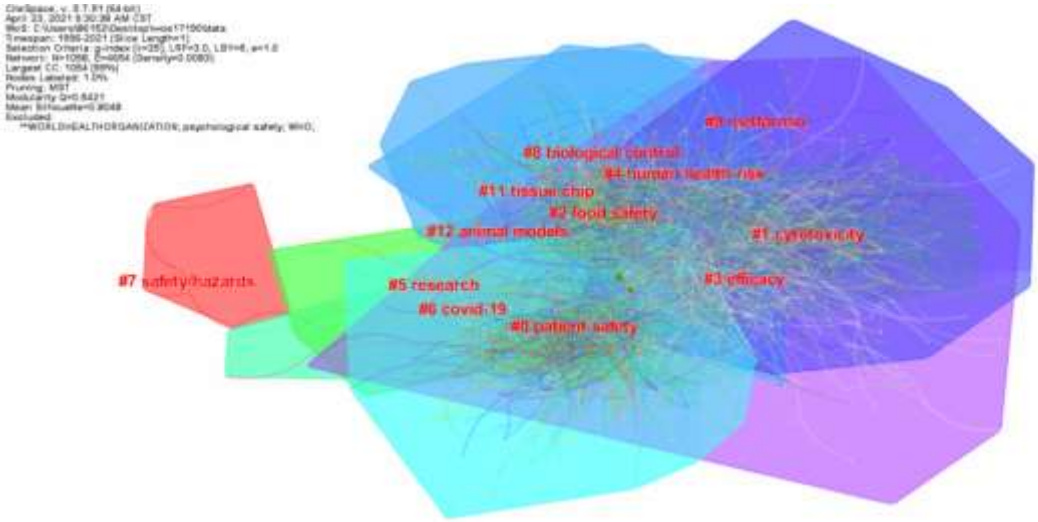

Figure 9: Cluster view of the safety culture keywords.

The largest cluster (#0) has 289 members and a silhouette of 0.879, which is labeled as patient safety by the LLR. Hot research topics for the patient safety culture (PSC) include assessing the current status of the PSC, researching the factors that influence the PSC, developing PSC evaluation tools, finding correlations between the PSC and outcome indicators, and improving PSC strategies. The second-largest cluster (#1) has 56 members and a silhouette of 0.959, which is labeled as cytotoxicity by the LLR. This mainly studies the cell resistance, mutation, and safety. The third-largest cluster (#2) has 224 members and a silhouette of 0.839, which is labeled as food safety by the LLR. The food safety evaluation is conducted primarily in the aspects of consumer behavior management system and control. The main evaluation methods include the use of measurements and statistical methods to establish models, pure index analysis, hazard analysis, logic model, EPA, extrapolation, and Monte Carlo simulation models.

The 4th largest cluster (#3) has 208 members and a silhouette of 0.782, which is labeled as efficacy by the LLR. This mainly focused on clinical medicine, basic medicine, and pharmacology to study the safety experimental effectiveness performance and related contents. The 5th largest cluster (#4) has 49 members and a silhouette of 0.949, which is labeled as human health risk by the LLR. The main relevant research is focused on the determination and assessment of human health risks, such as from the environment, food, drugs, and water.

The first item from the bursts was infection with a burst of 55.50. The second was therapy with a burst of 39.44. The third was mice with a burst of 25.02. The fourth was efficacy with a burst of 24.51. The fifth

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was gene therapy with a burst of 24.36. The sixth was expression with a burst of 21.36. The seventh was in vivo with a burst of 19.79. The eighth was young children with a burst of 19.54. The ninth was immunization with a burst of 18.66. The tenth was virus with a burst of 18.55.

The first ranked item from the centrality was rat with a centrality of 48. The second was antibody with a centrality of 46. The third was bacteremia with a centrality of 46. The fourth was clinical trials with a centrality of 45. The fifth was transplantation with a centrality of 45. The sixth was resistance with a centrality of 44. The seventh was prevention with a centrality of 44. The eighth was expression with a centrality of 43. The ninth was induction with a centrality of 43. The tenth was activation with a centrality of 43. Meanwhile, covid-19, biological control, metformin, tissue chips, and animal models are also hot research directions for safety culture research.

V. DOCUMENT CO-CITATION ANALYSIS

In 1973, Henry Small, an American intelligence scientist, published "Co-citation in the scientific literature: A new measure of the relationship between publications" [19] and introduced the concept of co-citation analysis. This refers to the fact that two documents appear together in the reference list of a third citing document. Then, these two documents form a co-citation relationship. The process of mining the literature co-citation relationships along the collection of literature space data is considered literature co-citation analysis.

5.1 Author co-citation analysis

In 1981, White and Griffith extended the co-citation of documents to the author level and developed the author co-citation analysis (ACA) research method [20]. The co-citation relationship network graph in Figure 10 as generated from CiteSpace shows the academic distance between scholars.

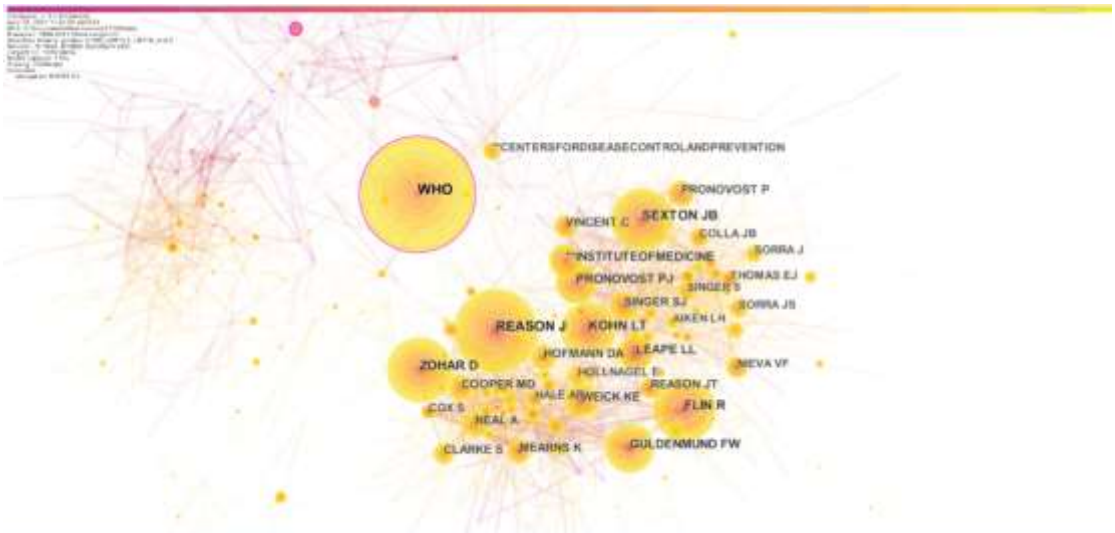

Figure 10: Co-citation knowledge graph of safety culture research authors.

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TABLE 5. Top 10 cited authors of safety culture.

Count	Centrality	Year	Cited Authors
962	0.1	1999	WHO
736	0.05	1996	Reason J
589	0.04	2000	Zohar D
554	0.02	2003	Sexton JB
536	0.03	2000	Flin R
528	0.01	2002	Kohn LT
464	0.03	2003	Guldenmund FW
397	0.07	2004	Pronovost PJ
362	0.04	2000	Leape LL
347	0.08	2002	Institute of Medicine

It is seen from Figure 14 that Who, Reason J, and Zohar D have the largest annual rings, which means their published papers have the highest co-citation frequency. Table 5 presents a list of credit evaluation method researchers based on the frequency of citations. It is seen that these authors' academic research results are the most influential.

5.2 Co-citation analysis of journals

The basic principle of journal co-citation analysis is to extract information about literature sources from references to create a co-citation network. Journal co-citation analysis provides the distribution of important knowledge sources in a field and helps users to answer questions about the lines of journals cited by research in the field, the relationships between journals, and the distribution of knowledge areas in the disciplines these journal groups are composed [21]. The journal co-cited nodes are selected and CiteSpace is run to generate Figure 11.

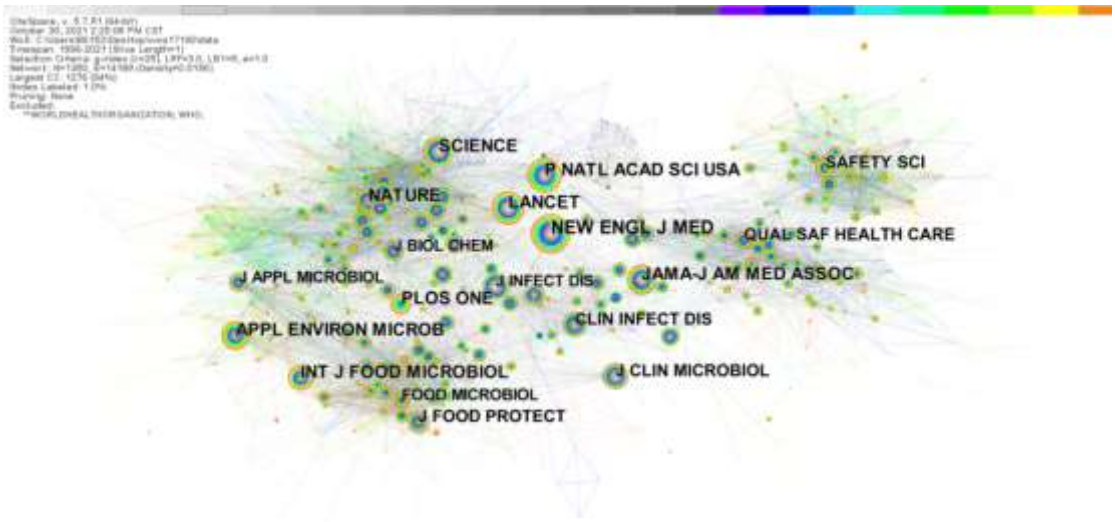

Figure 11: Co-citation knowledge graph of safety culture research journals.

TABLE 6. Top 10 cited journals of safety culture.

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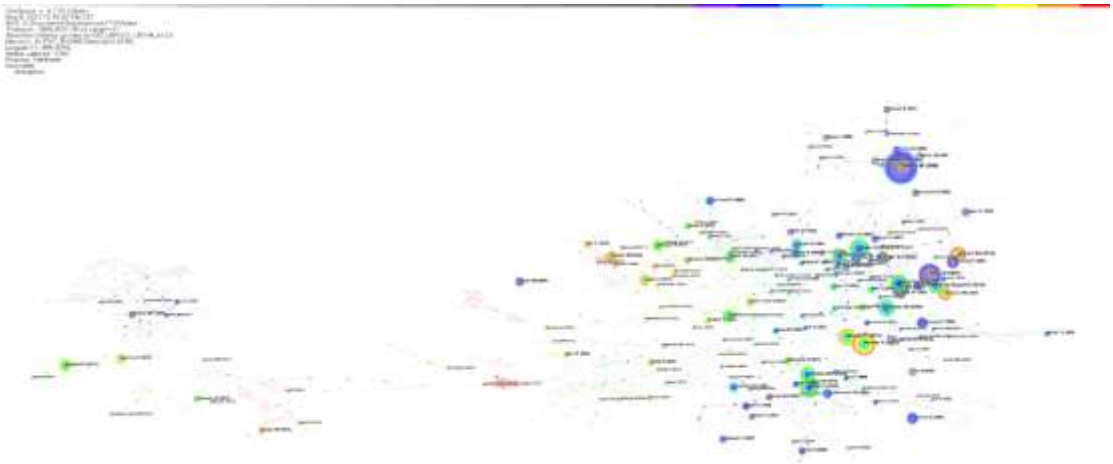
Count	Centrality	Year	Cited Journal
3267	0.03	1996	New Engl J Med
2731	0.01	2008	PLOS One
2615	0.02	1996	P Natl Acad Sci USA
2395	0.01	1996	Lancet
2192	0.02	1996	Appl Environ Microb
2130	0.01	1996	Science
2075	0.06	1996	JAMA-J Am Med Assoc
1988	0.03	1996	Int J Food Microbiol
1954	0.01	1996	Nature
1575	0.03	2004	Qual Saf Health Care

5.3 Co-citation analysis of literature

The research front in a certain field refers to the emerging theoretical trends and the emergence of new themes. In the document co-citation analysis, the collection of citing documents constitutes the research front related to these clusters. The 1,400 bibliographic recordings from 1996 to 2021 were visualized and a 1-year time slice was selected for the analysis. The top 50 most occurring or cited articles every three years were selected. The results are illustrated in Figure 12. There were 1,747 individual nodes and 2,465 links representing the cited articles and co-citation relationships in the entire dataset.



a.

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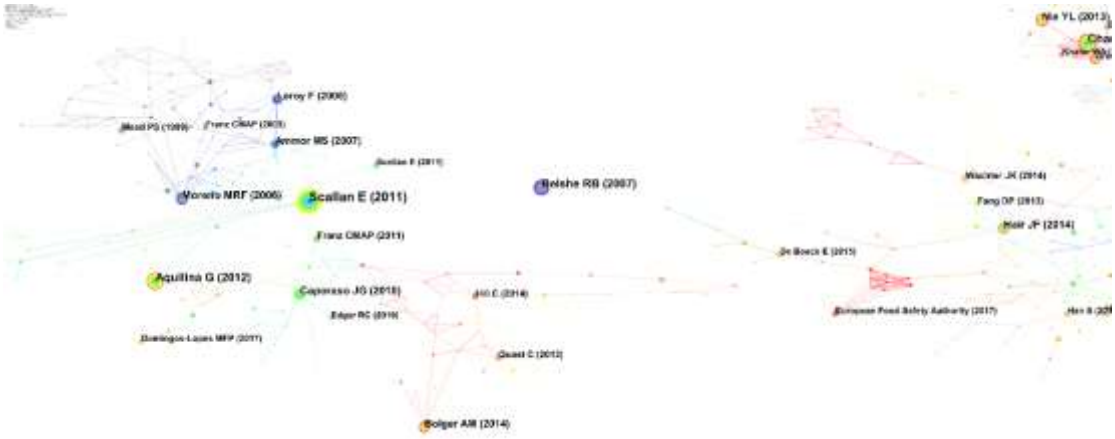
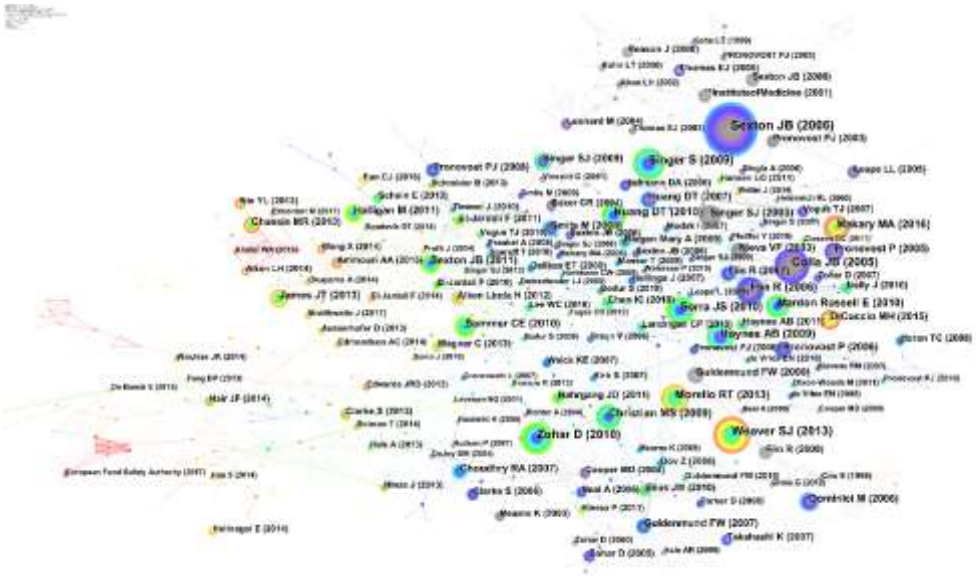


b.



c.

Figure 12: Safety culture reference co-citation network diagram

TABLE 7. The five top-cited articles in safety culture.

Cited frequency	Author (year)	Title	Source
158	Sexton JB (2006)	The safety attitudes questionnaire: psychometric properties, benchmarking data, and emerging research	Health Services Research
112	Weaver SJ (2013)	Promoting a culture of safety as a patient safety strategy: A systematic review	HHS Public Access
105	Colla JB (2005)	Measuring patient safety climate: A review of surveys	Measuring Patient Safety Climate
100	Zohar D (2010)	Thirty years of safety climate research: Reflections and future directions	Accident Analysis and Prevention

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94	Sara S (2008)	Relationship of safety climate and safety performance in hospitals	Health Research and Educational Trust

The most cited paper is from John B Sexton (2006) [22]. His paper reports on psychometric properties, establishes baseline data, and discusses the emerging research areas of the University of Texas Safety Attitudes Questionnaire (SAQ). Six cross-sectional surveys were administered to 203 health care professionals (n=10,843) in the clinical areas of three countries. Multilevel factor analyses yielded results at the clinical area level, which is where the respondents were nested. He reported on the scale reliability, floor/ceiling effects, item factor loadings, inter-factor correlations, and the percentage of respondents who agree with each item and scale. A six-factor model of provider attitudes matched the data at both the clinical area and respondents nested within. These factors were: Teamwork Climate, Safety Climate, Perceptions of Management, Job Satisfaction, Working Conditions, and Stress Recognition. The provider attitudes varied greatly both within and among the organizations. The SAQ demonstrated good psychometric properties. Healthcare organizations can use the survey to measure caregiver attitudes regarding six patient safety-related domains to compare themselves with other organizations, prompt interventions to improve safety attitudes, and measure the effectiveness of such interventions.

The second most cited paper is from Sallie J Weaver (2013) [23]. She searched MEDLINE, CINAHL, PsycINFO, Cochrane, and EMBASE to identify relevant English-language studies published from January 2000 to October 2012. Eight studies included the executive walk rounds or interdisciplinary rounds, eight evaluated multicomponent unit-based interventions, and 20 included team training or communication initiatives. Twenty-nine studies reported some improvement in safety culture or patient outcomes, but the measured outcomes were highly heterogeneous. The strength of evidence was low, and most studies were pre-post evaluations of low to moderate quality. Within these limitations, there is evidence that interventions can improve the perceptions of safety culture and potentially reduce patient harm.

The third most cited paper is from J B Colla (2005) [24]. He compared the general characteristics, dimensions covered, psychometrics performed, and uses in studies of patient safety climate surveys. Nine surveys measured the patient safety climate of an organization; however, these surveys varied widely. Achieving a culture that is conducive to patient safety may be an admirable goal, but more effort should be expended to understand the relationship between the measures of patient safety climate and patient outcomes. In the paper by Zohar D [25], he reviewed more than 30 years of research by himself and other safety-climate scholars. He proposed that we have achieved the enormous task of validating safety climate as a robust leading indicator or predictor of safety outcomes across industries and countries. Thus, the time has come to move to the next phase of scientific inquiry, where constructs are enhanced by testing their relationships with antecedents, moderators, mediators, and other established constructs.

Sara Singer (2008) [26] examined the relationship between hospital safety climate measures and hospital performance on select patient safety indicators (PSIs). A negative binomial regression was used as an unweighted risk-adjusted PSI composite as a dependent variable while the safety climate scores and controls were the independent variables. Some included specifications were interpersonal, work unit, and organizational safety climate dimensions. Others included separate measures for senior managers and frontline personnel safety climate perceptions. Hospitals with better overall safety climates had a lower

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relative incidence of PSIs, as did hospitals that scored higher on safety climate dimensions, which measure interpersonal perceptions regarding shame and blame. Perceptions of better safety climates by frontline personnel predicted lower risks of experiencing PSIs, but senior manager perceptions did not. The results link the hospital safety climate to the indicators of potential safety events. Some aspects of safety climates were more closely related to safety events than others. The perceptions of some groups (e.g., front-line employees) are more closely related to safety climates than those of other groups.

Based on the interconnectivity between nodes, the entire collection of bibliographic records generated the main clusters seen in Figure 17. The network is divided into 16 co-citation clusters, which are labeled through index terms from their own citers. This cluster map only shows the largest 10 clusters, and the largest 5 clusters are summarized.

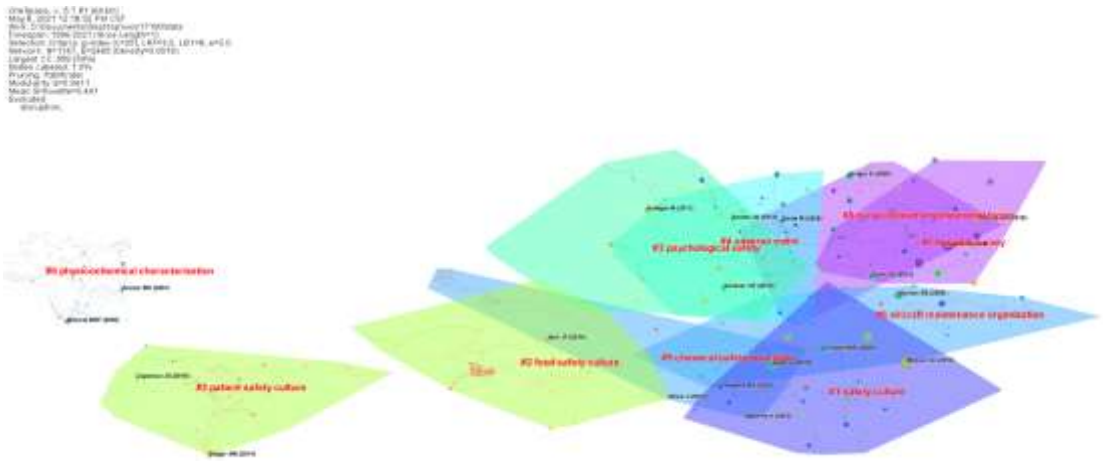

Figure 13: Cluster visualization based on a document co-citation network from 1996–2021.

Figure 13 shows the main clusters in the knowledge domain of safety culture. Among them, Clusters #0, #1, #2, #3, and #4 have the strongest citation bursts as dark dots, suggesting they constitute the major and active research efforts for this knowledge domain. The largest cluster (#0) has 88 members and a silhouette of 0.973, which is labeled as physicochemical characterization by the LLR. The five most active citers to the cluster are Giraffa, G (2003), Franz, CMAP (2003), Ammor, Mohammed Salim (2007), Klare, Ingo (2007), and Klein, G (2003). Giraffa (2003) [27] summarized the complex biochemical and ecological phenomena that explain the technological functionality of the enterococci in dairy products, which still need to be fully understood. The safety of dairy products that contain enterococci is an issue that the industry must carefully address before proceeding to their application. Franz (2003) [28] considered an Enterococcus strain as a starter or probiotic culture. Each particular strain must be carefully evaluated for the presence of all known virulence factors. E. faecium appears to have a lower risk for use in food products as there is a lower incidence of such virulence determinants among strains compared to E. faecalis strains. This is likely a result of the presence of pheromone-responsive plasmids.

Salim (2007) [29] discussed the techniques and new selection criteria in the selection of LAB starter cultures to produce fermented dry sausages. Klare (2007) [30] selected isolates that show acquired antimicrobial resistance(s) for the PCR-based detection of resistance gene(s) and in vitro conjugative

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transfer experiments. Tentative ECOFF values for 13 antibiotics were determined for up to 12 LAB species. The discovery of acquired resistance genes in isolates intended for probiotic or nutritional use highlights the importance of antimicrobial susceptibility testing when documenting the safety of commercial LABs. Klein (2003) [31] explored the need for reliable conventional phenotypic identification schemes for the simple and rapid determination of enterococcal species in food or the gastrointestinal tract (GIT). Only a limited number of enterococcal species is important for the ecology of the GIT or food microflora. Experts in the EU proposed safety criteria for probiotics in feed additives with the exclusion of resistances or the lack of transferability. Technologically used strains should differ from clinical strains in terms of their resistance patterns and transfer rates.

The second-largest cluster (#1) has 87 members and a silhouette of 0.964. The five most active members of this cluster are Paine, Lori A (2010), Guldenmund, Frank W (2010), de Wet, C (2010), Pfeiffer, Yvonne (2010), and Bahari, Siti Fatimah (2013). The most active member of this cohort at 13,351 co-citations is Paine, Lori A (2010) [32]. She designed and established a prospective cohort study using multiple interventions to improve the hospital-wide safety climate. The comprehensive unit-based safety program included steps to identify hazards, partner units with a senior executive to fix hazards, learn from defects, and implement communication and teamwork tools. The safety climate was assessed annually using a safety attitude questionnaire. Hospital-wide interventions were associated with improvements in the safety climate at a large academic medical center. Guldenmund (2010) [33] discussed three approaches to safety culture concepts. The culture concept is deprived of much of its depth and subtlety and is morphed into a grab bag of behavioral and other visible characteristics without reference to the meaning these characteristics may have. This is often infused with normative overtones.

We resurrect the notion of safety culture and strengthen its analytical potential to understand the development and implementation of safety management systems. de Wet (2010) [34] studied the first stage in developing appropriately valid and reliable safety climate measures for primary care. Measuring safety climate perceptions has the potential to help primary care organizations, and teams have focused attention on safety-related issues and targeted improvements through educational intervention. Further research is required to explore the acceptability and feasibility issues for primary care teams and the potential for organizational benchmarking. Pfeiffer (2010) [35] developed a German version of the Hospital Survey on Patient Safety Culture (HSOPSC) and investigated its dimensionality and predictive validity. The relationship between the safety climate and outcome variables was investigated via regression analyses. For physicians and nurses, different predictors were identified for the overall safety climate perception. The findings highlight the importance of capturing the impact of different management levels, especially in large hospitals, and differences between professional groups to design interventions accordingly. Bahari (2013) [36] concluded that the safety climate model is cross-validated in Malaysian manufacturing samples. The CFA found the hypothesized model to be a poor fit, and the EFA was used to develop a new three-factor safety climate model. The differences are explained with reference to variations in national cultures. Thus, there are implications for multinationals that implement safety climate surveys across cultures.

The third-largest cluster (#2) has 86 members and a silhouette of 0.966, which is labeled as food safety culture by the LLR. The five most active citers in the cluster are de Andrade, Marcel Levy (2020),

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Nyarugwe, Shingai P (2020), Mohammadi, Amir (2020), Wu, Sophie Tongyu (2020), and Tomasevic, Igor (2020). The most active citation for this cluster is 1,281 for Marcel Levy de Andrade (2020) [37], which emphasizes that all food safety culture elements show reasonable internal consistency. Food safety culture was improved in restaurants at low risk for foodborne disease. The organizational commitment was better perceived in low-risk restaurants, and all food handlers were optimistic regarding the risk of foodborne disease. Nyarugwe (2020) [38] argued that the prevailing food safety culture appears independent of product riskiness. Food safety governance could explain the prevailing food safety culture, and multinational companies have a better food safety culture than local companies. Mohammadi (2020) [39] identified the behavioral safety patterns of construction workers. The identified archetypes are illustrated using system dynamics. The archetypes help managers become aware of the long-term effects of their decisions and depict the dynamic complexity of construction safety management. Wu (2020) [40] concluded that there is a significant correlation between food safety culture and the risk of Listeria monocytogenes contamination. Employee-executed deep cleaning significantly improved short- and long-term food safety culture. Differences in perceiving food safety programs were observed between retail deli managers and associates. Tomasevic (2020) [41] surveyed 503 food companies in 10 countries, which showed the overall food safety climate. The food safety climate was better in larger companies, and there was no influence of the national culture on the food safety climate. However, EU companies had better climates than non-EU companies.

The 4th largest cluster (#3) has 84 members and a silhouette of 0.941, which is labeled as psychological safety by the LLR. The five most active citers to the cluster are Bodur, Said (2010), Kaya, Sidika (2010), Paine, Lori A (2010), Lee, Wui-Chiang (2010), and Sawyer, Melinda (2010). The most active citer to the cluster was 1,2781 for Bodur, Said (2010) [42]. He determined the validity and reliability of the translated form of HSOPS to evaluate physicians' and nurses' perceptions of patient safety in Turkish public hospitals compared with hospital settings in the United States. The Turkish version of HSOPS was valid and reliable to determine patient safety culture. This tool will help track improvements and heighten awareness of patient safety culture in Turkey. Kaya (2010) [43] suggested that examining differences in perceptions of safety and providing baseline data is important to test the psychometric soundness of the SAQ in Turkish hospitals. The SAQ (inpatient version) was translated with the back-translation technique into Turkish, which showed satisfactory internal psychometric properties. Attitudes relevant to safety culture vary widely by hospital and indicate a need for improvement.

Certain studies provide a baseline for future benchmarking. Paine, (2010) [32]designed and set a prospective cohort study using multiple interventions to improve the hospital-wide safety climate. The safety climate was assessed annually using the SAQ with response rates of 77% (2006) and 79% (2008). Hospital-wide interventions were associated with improvements in the safety climate at a large academic medical center. Lee (2010) [44] verified a safety culture survey instrument in Chinese and assessed hospital safety culture in Taiwan. The Taiwan Patient Safety Culture Survey was conducted in 2008 using the adapted SAQ in Chinese (SAQ-C). This verified the psychometric properties of the SAQ-C at Taiwanese hospitals The author concluded that safety culture in most hospitals in Taiwan has not yet fully developed and there is considerable room for improvement. Sawyer (2010) [45] implemented a program relevant to hospital infections, called On the CUSP: Stop BSI, which was formulated from the Michigan

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project. The model in this program balances the tension between being scientifically rigorous and feasible. The three main components of the model include translating evidence into practice at the bedside to prevent central catheter-associated bloodstream infections, improve culture and teamwork, and provide a data collection system to monitor central catheter-associated bloodstream infections and other variables. If successful, this program will be the first national quality improvement program in the United States with quantifiable and measurable goals.

The 5th largest cluster (#4) has 73 members and a silhouette of 0.974, which is labeled as adverse event by the LLR. The five most active citers to the cluster are Kaya, Sidika (2010), Bodur, Said (2010), Haugen, Arvid S (2010), Titi, Maher Abdelraheim (2021), and Gurkova, Elena (2020). The most active citer at 10,341 is Kaya (2010) [46]. In his paper, the SAQ (inpatient version) was translated into Turkish using a back-translation technique, and the factor structure of the responses was tested using confirmatory factor analysis. Cronbach alphas were calculated and the mean and percent positive safety attitude scores were assessed. The response rate was 67.5%. The Cronbach alphas for six factors (teamwork climate, safety climate, job satisfaction, stress recognition, perceptions of management, and working conditions) ranged from 0.66 to 0.77. The goodness-of-fit indices from the confirmatory factor analysis were reasonable. The Turkish translation of the SAQ showed satisfactory internal psychometric properties. Attitudes relevant to safety culture vary widely by hospital and indicate a need for improvement, and survey findings provide a baseline for future benchmarking. Bodur (2010) [42] translated the HSOPS into Turkish to study patient safety culture in Turkish hospitals. The Turkish version of HSOPS was found to be valid and reliable in determining patient safety culture. This tool helps track improvements and heightens awareness of patient safety culture in Turkey. Haugen (2010) examined the psychometric properties of a Norwegian translation of HSOPS and compared safety climate factors from a surgical setting between hospitals in the United States, the Netherlands, and Norway. the professions differed in their perceptions of patient safety climate, with anesthesia personnel having the highest mean scores. The psychometric properties of the questionnaire need further investigations to be regarded as reliable in surgical environments. The operating theatre personnel perceived their hospital's patient safety climate far more negatively than health care personnel in hospitals from the United States with perceptions more comparable to those of health care personnel in hospitals from the Netherlands.

Titi (2021) [47] examined how the results of an HSOPS culture changed between 2012 and 2019 and identified organizational factors that affect these changes. The primary and secondary outcome measures were used to assess 12 safety culture dimensions to study the patient safety culture as perceived by healthcare professionals. An additional semi-structured interview was performed to identify organizational factors, changes, and barriers that affect patient safety culture. Furthermore, suggestions to improve patient safety were proposed. Comparing the results revealed a generally positive trend in scores from 2012 to 2019. The areas of strength include teamwork within and across units, organizational learning, managerial support, the overall perception of safety and feedback, and communications about errors. Non-punitive responses to error, staffing, and communications and openness consistently remain the lowest-scoring composites. The interview results suggest that organizational changes may influence the answers of participants on some survey composites.

Patient safety is a moving target with areas for improvement that are continuously identified. Effective

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quality improvement initiatives can lead to visible changes in patient safety culture in hospitals, and consistent leadership commitment and support can maintain these improvements. Gurkova (2020) [48] examined variations in the safety climate as reported by nurses in Slovak hospitals and analyzed the association between the dimensions of patient safety climate, demographics, and organizational factors. The HSOPS questionnaire was used for data collection, and a descriptive analysis was performed to examine the relationships between variables. Nurses perceived higher levels of patient safety when they experienced better information sharing on event reporting and had better learning opportunities. The results show the strengths and weaknesses of the patient safety climate in the Slovak hospital network. This knowledge may allow nurse leaders to adopt supportive strategies for incident reporting and learning in the context of enhancing a culture of safety.

The top-ranked item by bursts is Sexton JB with a burst of 43.16. The second is Colla JB with a burst of 31.27. The third is Makary MA with a burst of 29.19. The fourth is Singer SJ with a burst of 27.92. The fifth is Guldenmund FW with a burst of 27.03. The sixth is Flin R with a burst of 25.63. The seventh is Singer S with a burst of 24.16. The eighth is Weaver SJ with a burst of 23.43. The ninth is Zohar D with a burst of 22.93. The tenth is DiCuccio MH with a burst of 22.92.The top-ranked item by centrality is Brown MS with a centrality of 19. The second is Alberts AW with a centrality of 19. The third is Bernini F with a centrality of 19. The fourth is Blum CB with a centrality of 19. The fifth is Blankenhorn DH with a centrality of 19. The sixth is Corsini A with a centrality of 19. The seventh is Bocan TMA with a centrality of 19. The eighth is Brown G with a centrality of 19. The ninth is Catapano AL with a centrality of 19. The tenth is Arai M with a centrality of 19.

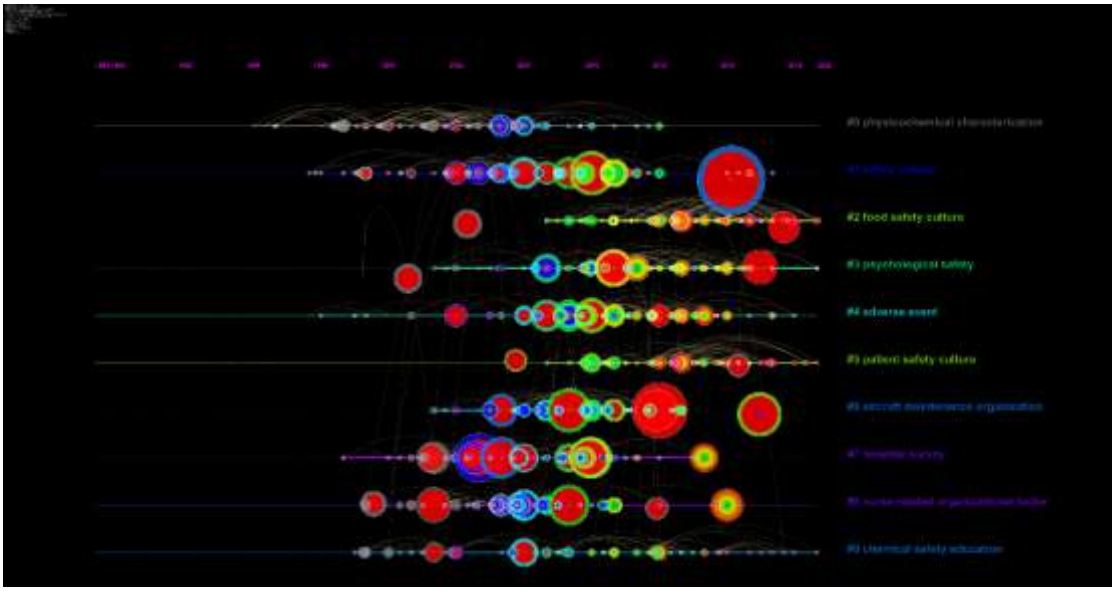

Figure 14: Timeline view of the safety culture cognition knowledge domain.

A timeline view is another research method. The results shown in Figure 14 are consistent with the cluster analysis. Burst detection can be used to explore the trends of a research field, and recent ongoing bursts reveal the future trends to some extent. This study also adopts this algorithm to extract citation

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bursts, and all citation bursts since 1996 were selected for analysis to explore the emerging trends of safety culture. Table 8 arranges the references in terms of citation the bursts' strength and the year that marks the beginning of the burst.

TABLE 8. Top 25 references with the strongest citation bursts from 1996 to 2021.

Reference	Year	Strength	Begin	End	1996 - 2021
Singer SJ, 2003, QUAL SAF HEALTH CARE, V12, P112, DOI	2003	**16.8505**	2005	2008	
Nieva VF, 2003, QUAL SAF HEALTH CARE, V12, P0, DOI	2003	**12.7703**	2005	2008	
Wolfe, A. 2001, CROSS QUAL CHASM NEW, V0, P0	2001	**12.5855**	2002	2006	
Guldenmund FW, 2000, SAFETY SCI, V34, P215, DOI	2000	**10.259**	2000	2005	
Baker GR, 2004, CAN MED ASSOC J, V170, P1678, DOI	2004	**9.6172**	2005	2009	
Reason J, 2000, BMJ-BRIT MED J, V320, P768, DOI	2000	**8.8105**	2002	2005	
Sexton JB, 2000, BMJ-BRIT MED J, V320, P745, DOI	2000	**7.7249**	2003	2005	
Flin R, 2000, SAFETY SCI, V34, P177, DOI	2000	**7.3985**	2001	2005	
Hacein-Bey-Abina S, 2003, SCIENCE, V302, P415, DOI	2003	**6.7744**	2004	2008	
Vincent C, 2001, BRIT MED J, V322, P517, DOI	2001	**6.7436**	2003	2006	
Hayden FG, 1997, NEW ENGL J MED, V337, P874, DOI	1997	**6.4246**	1999	2002	
Edmondson AC, 2004,Management Studies, V40, P66	2004	**6.2684**	2002	2007	
Aymerich T, 2003, APPL ENVIRON MICROB, V69, P4583, DOI	2003	**5.7947**	2005	2008	
Silagy C, 1998, LANCET, V352, P1877	1998	**5.3341**	2001	2002	
Treanor JJ, 2000, JAMA-J AM MED ASSOC, V283, P1016, DOI	2000	**5.3341**	2001	2002	
Dunbar CE, 1995, BLOOD, V85, P3048, DOI	1995	**5.2693**	1996	1998	
Cox S, 1998, WORK STRESS, V12, P189, DOI	1998	**5.091**	2000	2003	
Kohn LT, 2000, ERR IS HUMAN BUILDIN, V7,P245	2000	**4.6212**	2004	2005	
Belshe RB, 1998, NEW ENGL J MED, V338, P1405, DOI	1998	**3.9994**	2001	2002	
Shapiro AMJ, 2000, NEW ENGL J MED, V343, P230, DOI	2000	**3.9604**	2004	2005	
Banchereau J, 2000, ANNU REV IMMUNOL, V18, P767, DOI	2000	**3.9604**	2004	2005	
Kuehnert MJ, 2001, TRANSFUSION, V41, P1493, DOI	2001	**3.8675**	2005	2006	
Weltzin R, 2003, NAT MED, V9, P1125, DOI	2003	**3.8675**	2005	2006	
Barach P, 2000, BMJ-BRIT MED J, V320, P759, DOI	2000	**3.6961**	2001	2005	
Covalciuc KA, 1999, J CLIN MICROBIOL, V37, P3971, DOI	1999	**3.3324**	2001	2002	

The most striking trend is the role of basic theoretical research on the four categories of the function, characteristics and classification of safety culture; elements and structure of safety culture; evaluation of safety culture; construction of safety culture; and other basic theoretical research. The second category focuses on high-risk industries and high-reliability organizations, such as the nuclear and mining industries. It gradually expands and extends to areas such hospital, food, building, traffic, and campus safety cultures. The third category discusses the entire system down to a single variable. The last category focuses on the contributions of the generalized safety culture; that is, the study of preventive safety culture.

VI. DISCUSSION AND CONCLUSION

This paper analyzed the annual distribution of the security culture research papers in the WoS database using the CiteSpace visualization tool; analyzed the cooperation network of countries, institutions, and authors; and performed co-occurrence and co-citation analyses. The development trends in the field of safety culture were determined, and the results are summarized as follows:

1.The number of papers published on safety culture research has increased significantly, indicating that its attention is increasing. The research power is concentrated primarily in countries such as the United States and England Core publications on safety culture, such as Safety Science, Quality & Safety in Health

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Care, Journal of Applied Psychology, British Medical Journal, and other important international journals or top journals show the status of publications that carry academic achievements in safety culture. Most publications are in international journals with important influence.

2.The research hotspots of safety culture are patient safety, efficacy, food safety, covid-19, hazards, biological control, metformin, tissue chip, animal models.

3.The research trends of safety culture mainly include continually studying the basic theories in depth, shifting from high-risk industries to conventional industries, global to single variables, and research on prevention culture.

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