ANKARA SCIENCE UNIVERSITY, RESEARCHER
Vol. 4, No. 2, Decmber 2024
e-ISSN: 2717-9494
Research Article/Araştırma Makalesi

Functional Resonance Analysis Method for the Manufacturing Industry: A Bibliometric Analysis of the Literature

Nazlı Gülüm MUTLU[1*]
[1] Bingol University, Department of Occupational Health and Safety, Bingol, Turkey; ORCID: 0000-0003-0210-5175
* Corresponding Author: ngmutlu@bingol.edu.tr

Received: 5 March 2024; Accepted: 23 July 2024

Reference/Atıf: N. G. Mutlu, "Functional Resonance Analysis Method for the Manufacturing Industry: A Bibliometric Analysis of the Literature", Researcher, vol. 04, no. 02, pp. 120–129, 2024.

Abstract

The manufacturing industry is a socio-technical system with high and medium-high technology, and companies within these sectors aim to enhance their capabilities to maintain a competitive edge and ensure long-term sustainability. Organizational performance plays a crucial role in the ecosystem, but performance outcomes may not always align with continuous planning due to changes that can occur. Therefore, managing variability based on the human factor, particularly in the manufacturing industry, which has a significant impact on the national economy, is a top priority when developing solutions to address the challenges faced by these sectors. The Functional Resonance Analysis Method (FRAM) is a safety analysis technique that aims to analyze variability that causes deviations and well-performing situations. This study conducts a bibliometric analysis to provide insight into studies that have benefited from FRAM in the manufacturing industry. The study found that 52% of published works are journal articles, and Tarcisio Abreu Saurin and Eric Hollnagel are the most prominent authors in the field. For researchers, the top three journals for publishing and citing are Safety Science, Reliability Engineering & System Safety, and Ergonomics, respectively. Brazil, China, and Italy lead in the number of publications, with a limited number coming from Turkey. To identify research gaps, it is suggested that researchers use keywords such as FRAM, socio-technical systems, and resilience engineering. The results of this study are expected to motivate future research that will support the long-term viability of Turkey manufacturing industry, particularly.

Keywords: Manufacturing industry, socio-technical systems, safety analysis, FRAM, bibliometric analysis

1. Introduction

According to the NACE Rev.2 guide, manufacturing comprises 24 divisions [1]. While manufacturing is considered a substantial alteration, renovation, or reconstruction of materials, the output of the manufacturing process can either be ready for consumption or, in the form of semi-finished goods, serve as input for further manufacturing. Additionally, the assembly of the component parts of manufactured or purchased products is considered in manufacturing. Contemporary manufacturing systems are classified into five groups: cellular manufacturing, computer-aided manufacturing, just-in-time manufacturing, flexible manufacturing, and optimized manufacturing systems [2]. The manufacturing industry plays a crucial role in the economic development of countries [3, 4]. The sectors within it are known to possess high and medium-high levels of technology, which is a well-established fact [5]. Manufacturing companies typically prioritize investments in technology to maintain a competitive edge and enhance productivity [6, 7]. Adapting to rapidly evolving technology and understanding the social and technical components of the system, along with their functions, interactions, and potential threats, are essential for maintaining the continuity of the current state [8, 9]. In previous studies, it has been reported that occupational accidents affecting the safety and health of workers in the manufacturing industry are prominent, ranking among the top issues in different sectors [10–13] Additionally, occupational diseases in the manufacturing industry have been emphasized as significant [14]. The data presented in Figure 1 indicates that the number of accidents per person employed in the manufacturing industry in Turkey is roughly twice as high as the ratio observed in EU member countries. The need for analyzing hazards in the manufacturing sector is unquestionably acknowledged.

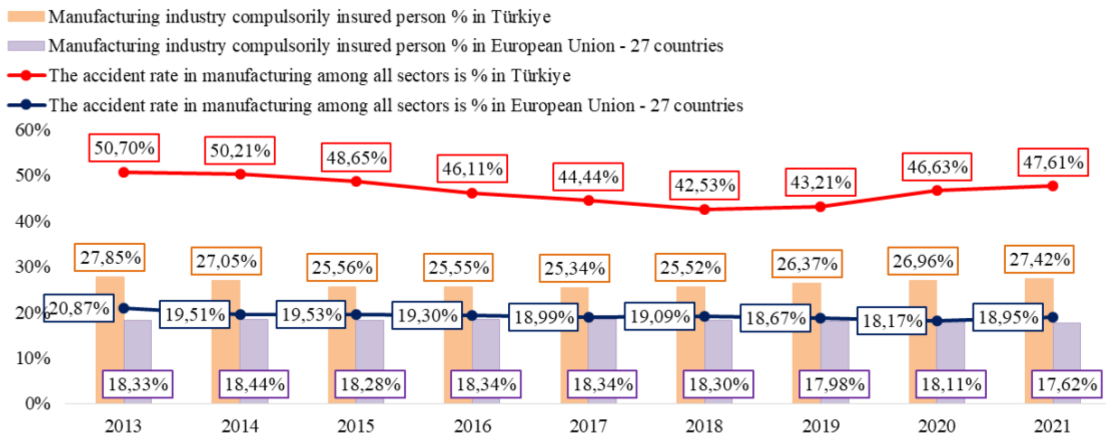

Figure 1: The percentage of employee and accidents for the manufacturing industry in Turkey and Europen Union-27 countries [15, 16]

Safety analysis methods can be divided into two perspectives: Safety-I and Safety-II. Safety-I is based on the idea that identifying the causes of negative outcomes and reducing or eliminating their occurrences will enhance safety, and all accidents can be prevented by avoiding unwanted events in this way [17]. The notion that individual or collective human performance is always variable weakens the belief that eliminating causes alone is sufficient for improving safety [17]. The Functional Resonance Analysis Method (FRAM), proposed by Hollnagel [18], is a safety analysis method based on the Safety-II perspective. It assists in managing functions, interactions among them, and potential undesired effects on complex socio-technical systems, contributing to the enhancement of system safety. FRAM also provides reactive analysis, such as the examination of historical accident records [19, 20]. In FRAM, a function is characterized by six aspects: input (I), output (O), preconditions (P), resources (R), time (T), and control (C) [18]. The Figure 2 demonstrates an example Functional Resonance Analysis Method (FRAM) for a system comprised of four functions. In this scenario, the Output of Function-1 serves as the Control for Function-3, while the Output of Function-2 acts as the Input for Function-3. Lastly, the Output of Function-4 represents the Resources required for Function-3.

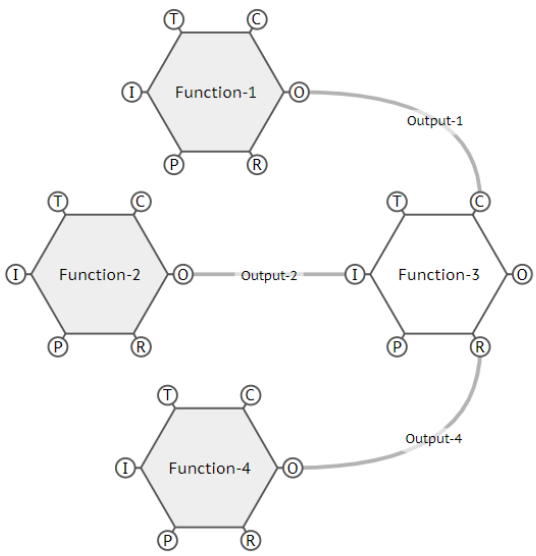

Figure 2: Example of FRAM model consist of four functions,

In a study carried out by Patriarca et al. [21], a thorough examination of the literature on FRAM was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA).

The results revealed that the top three sectors where FRAM applications are most prevalent are Aviation, Healthcare, and Industrial Operations. Among the literature reviews focusing on FRAM applications, there are studies such as those by McGill et al. [22] on FRAM applications in healthcare and Salehi et al. [23] on modeling complex socio-technical systems using FRAM. It is worth noting that no specific research has been conducted to investigate FRAM applications in the manufacturing industry. Therefore, this study aims to provide a quantitative overview of FRAM studies in the manufacturing industry through numerical indicators, providing researchers with a comprehensive perspective.

2. Method and Material

This research aims to provide a comprehensive perspective, supported by quantitative data, on the literature regarding the application of FRAM in the manufacturing industry. The decision to focus on the manufacturing industry was made based on the statistical classification of economic activities in the European Community Guide prepared by Carré [1]. Keywords were selected for the query based on relevant sectors and definitions within the industry. The query (ALL("Functional Resonance Analysis Method") AND ALL("manufacture systems") OR ALL("manufacturing systems") OR ALL("assemble systems") OR ALL("production systems") OR ALL("manufacturing industry")) AND PUBYEAR > 2012 AND PUBYEAR < 2024) was executed in the Scopus database on January 1, 2024. However, the five publications for the year 2024 were not included in the study, as the year had not yet been completed. In total, 92 publications of various types, published between 2013 and 2023, were included in the study. The dataset was analyzed using VOS viewer, a widely used tool in bibliometric analysis studies [24–26]. The main results of the analysis included co-authorship of authors, citation of authors, citation of countries, co-occurrence of author keywords, bibliographic coupling of documents, and bibliographic coupling of authors.

3. Results

The prevalence of publications utilizing the Functional Resonance Analysis Method within the manufacturing sector is depicted in Figure 3. A considerable proportion of these publications comprised of journal articles, whereas conference papers were less than half the number of journal articles. Upon analyzing the distribution of research by subject area, it was observed that the top three areas were engineering, computer science, and social science.

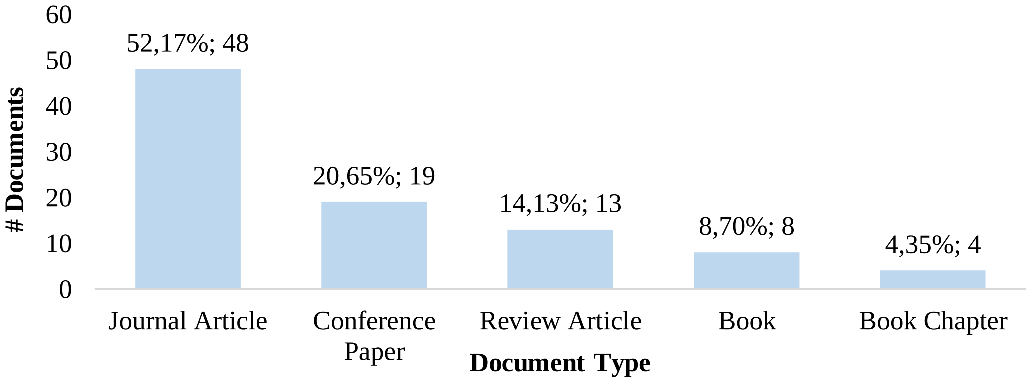

Figure 3: Documnet type in the dataset

In analyzing the publications related to FRAM in the manufacturing industry, a threshold of at least one publication and one citation was established for co-authorship. The study of shared authorship publications revealed that 25 authors were grouped into five clusters, comprising a total of 102 links and 104 total link strengths. The clusters to which the authors belong, along with the links, total link strength, and documents, are presented in Table 1. Tarcisio Abreu Saurin ranked first in terms of shared authorship publications, citations, links, and total link strength. The network map for the co-authorship of authors is illustrated in Figure 4. Although Ricardo Patriarca and Sylvie Nadeau, who each contributed six documents, are among the top three authors with the highest number of documents, and

Patrick Waterson and Peter Underwood, who each received 286 and 171 citations respectively, are among the top three authors with the most citations, they are not among the most connected authors as depicted in Figure 4.

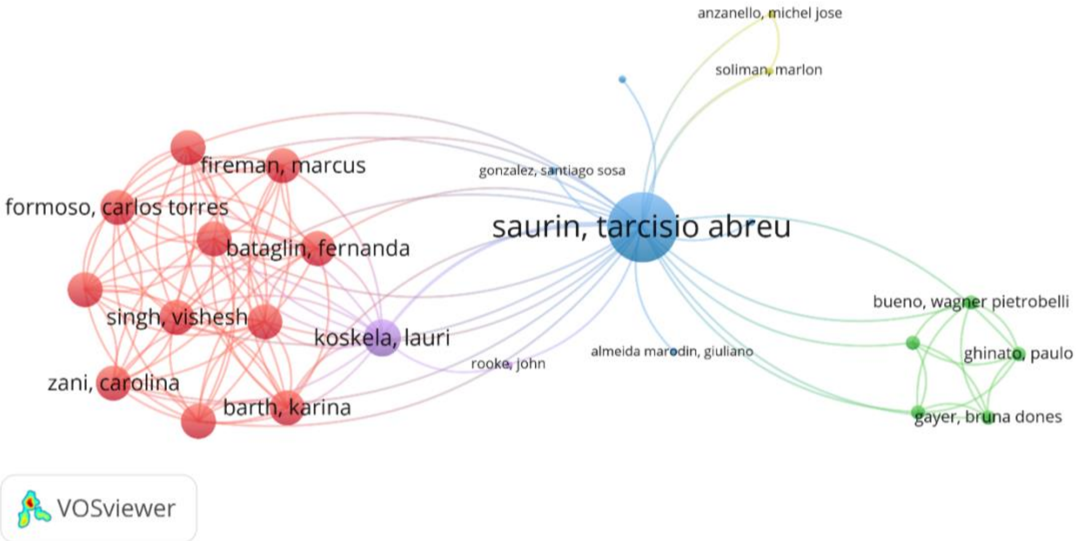

Figure 4: Map for co-authorship of authors

Table 1: The cluster for co-authorship of authors

Cluster number	**Cluster color**	**# Authors**	**# Links for each one author**	**# Total link strength for each one author**	**# Documents for each one author**
1	Red	11	12	12	1
2	Green	5	5	5	1
3	Blue	4	1	1	1
		Tarcisio Abreu Saurin	24	26	**10**
4	Yellow	Michel Jose Anzanello	2	2	1
		Marlon Soliman	2	3	2
5	Violet	2	2	2	1

To assess the citation networks of authors, a citation analysis was conducted with a minimum threshold of one publication and one citation per author. Among the 76 authors, 380 links were identified, and they were grouped into six clusters. The 22 authors in Cluster 1 (red color) were followed by 15 authors in Cluster 2 (green color), 12 authors in Cluster 3 (blue color), 10 authors each in Cluster 4 and Cluster 5 (yellow and violet colors, respectively), and seven authors in Cluster 6 (turquoise color). The top three authors with the most citations are listed in Table 2. Tarcisio Abreu Saurin led in terms of the number of publications, citations, and total link strength. The network map of the citations among the authors is presented in Figure 5.

Table 2: Top 3 for citation of authors

Cluster number	**Cluster color**	**Authors**	**Documents**	**Links**	**Citations**	**Total link strength**
2	Green	Tarcisio Abreu Saurin	10	24	394	58
1	Red	Patric Waterson	2	24	286	43
3	Blue	Sylvie Nadeau	6	23	12	35

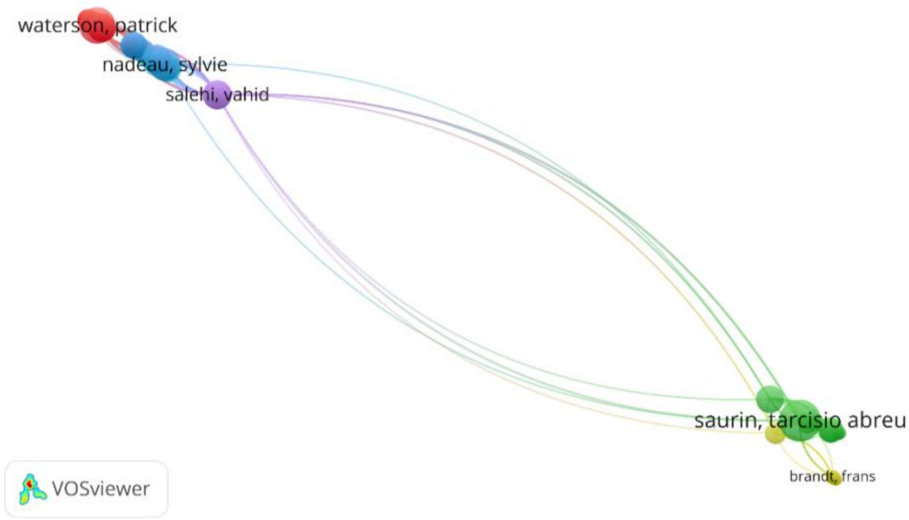

Figure 5: Map of citation of authors

To examine the network map of countries that produced, received citations, and had relationships among them, a threshold was set requiring at least one publication produced and one citation received by each country. A total of 14 countries were identified with relationships among them, forming five clusters within their own. There were 34 links between these countries. The United Kingdom had the most citations, while Brazil had the most documents. The network map of the citations among countries is shown in Figure 6. Turkey is included in Cluster 1, which has three documents, 37 citations, and a total link strength of three.

Table 3: Top 3 for citation of countries

Cluster number	Cluster color	Countries	Documents	Link	Citation	Total link strength
1	Red	United Kingdom	6	11	**496**	**28**
3	Blue	Canada	9	9	93	**24**
2	Green	Brazil	**18**	7	**457**	**18**
3	Blue	China	**13**	4	169	9
4	Yellow	Italy	**12**	6	**249**	14

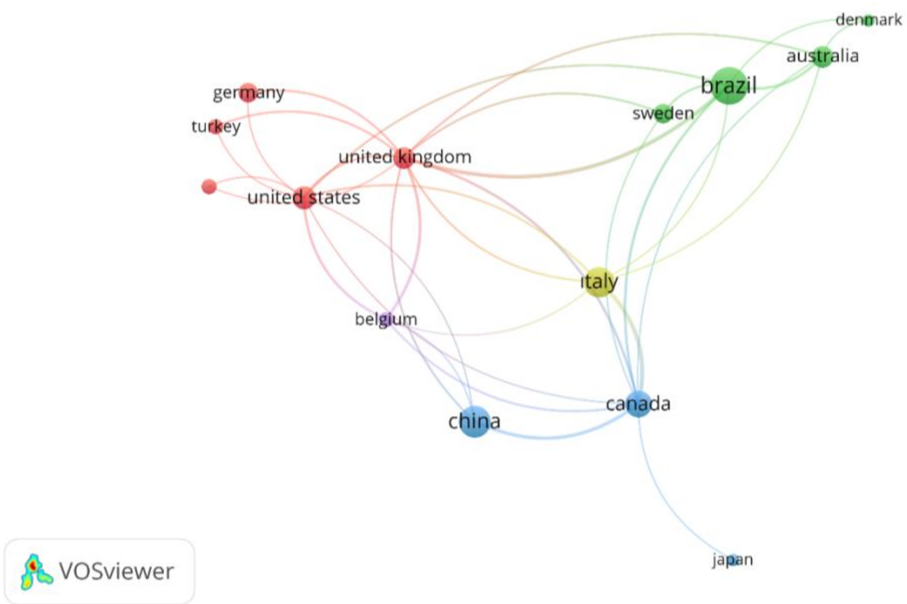

Figure 6: Map of citation of countries based on # document

The research conducted on "Co-occurrence of author keywords" uncovered the categorization of at least two related and observed keywords into seven distinct clusters, resulting in a total of 136 connections between them. Table 4 showcases the top three keywords in terms of overall link strength. Moreover, the network map portraying the co-occurrence of author keywords is illustrated in Figure 7.

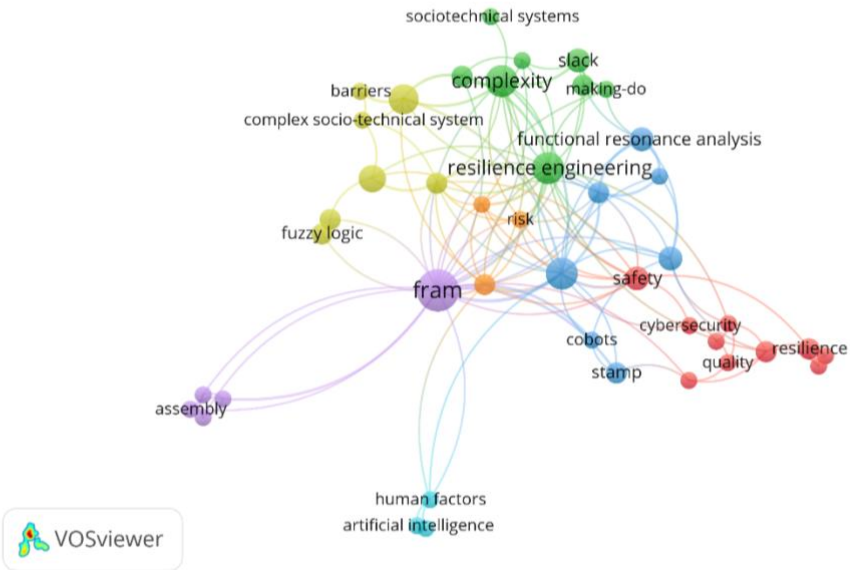

Figure 7: Map of co-occurence of authors keywords

Table 4: The top three keywords for co-occurrence of author keywords

Cluster number	Cluster color	Keyword	# Occurrences	Total link strength
5	Violet	fram	12	32
3	Blue	socio-technical systems	7	25
2	Green	resilience engineering	7	22

In conducting the analysis of "bibliographic coupling of authors", it was stipulated that an author must have produced at least one publication and received at least one citation. The resulting network map displayed in Figure 8 indicates that 211 authors were grouped into 17 clusters, which represent various aspects of FRAM research in manufacturing. The largest cluster, comprising approximately 29% of the articles, was centered around Tarcisio Abreu Saurin. A network map for the bibliographic coupling of the authors is visible in Figure 8.

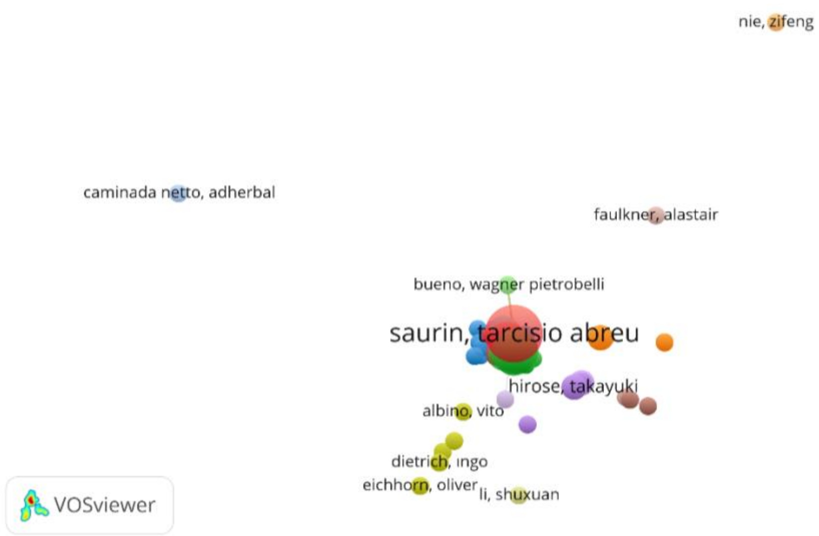

Figure 8: Map of bbibliographic coupling of authors

The network map for the "Co-citation of cited authors" analysis, considering publications where an author received at least 10 citations, is depicted in Figure 9. This map shows that 116 authors are interconnected, forming five clusters. Although Tarcisio Abreu Saurin was the dominant author in the bibliographic coupling of authors, Hollnagel E. emerged as the most frequently cited author among them. The distribution of citations among the authors was more balanced (see Table 5).

Table 5: The top co-cited publications based link and total link strength

Cluster number	Cluster color	Authors	Link	Citations	Total link strenght
4	Yellow	Hollnagel E.	114	291	12841
3	Blue	Patriarca R.	108	100	5957
4	Yellow	Abreu Saurin T.	102	86	3027

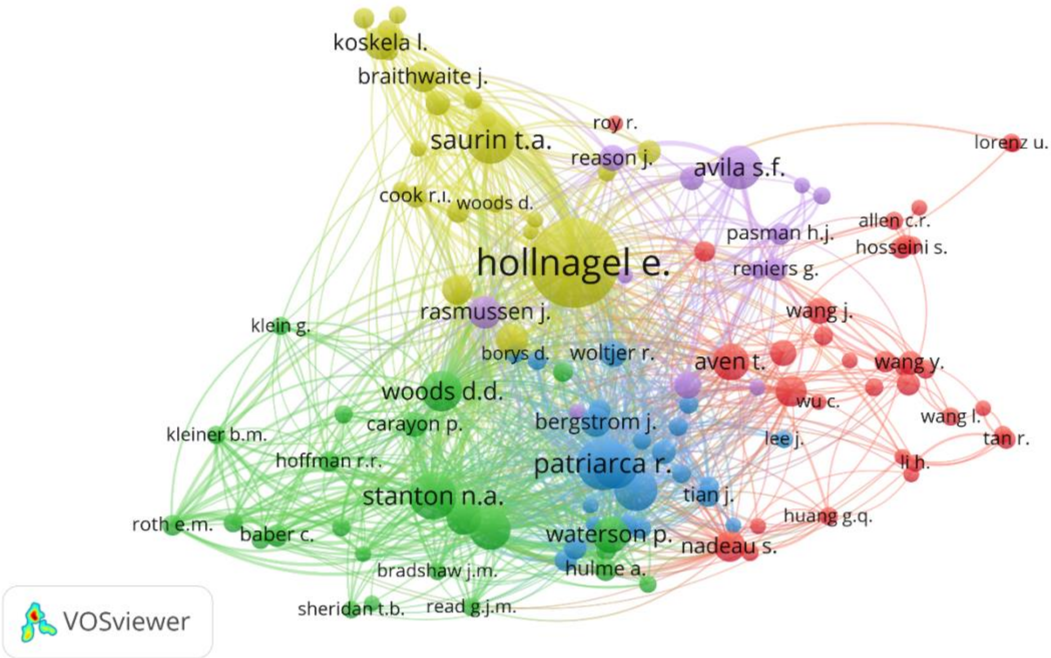

Figure 9: Map of co-citation of cited authors

The "bibliographic coupling of documents" analysis, which involves identifying works that have been cited by at least two independent sources, was conducted with a minimum threshold of one citation. This analysis resulted in the identification of 72 linked publications, which were grouped into eight clusters, and a total of 1043 links and a total link strength of 2265. The three publications with the highest bibliometric matching are Underwood (2013), with 171 citations, Waterson (2015), with 115 citations, and Almeida Marodin (2015), with 97 citations. In terms of total link strength, the top three publications are Braithwaite (2018), with a total link strength of 336, Hollnagel (2018), with a total link strength of 330, and Adriaensen (2019), with a total link strength of 162. The network map for the "Bibliographic coupling of documents" analysis is provided in Figure 10.

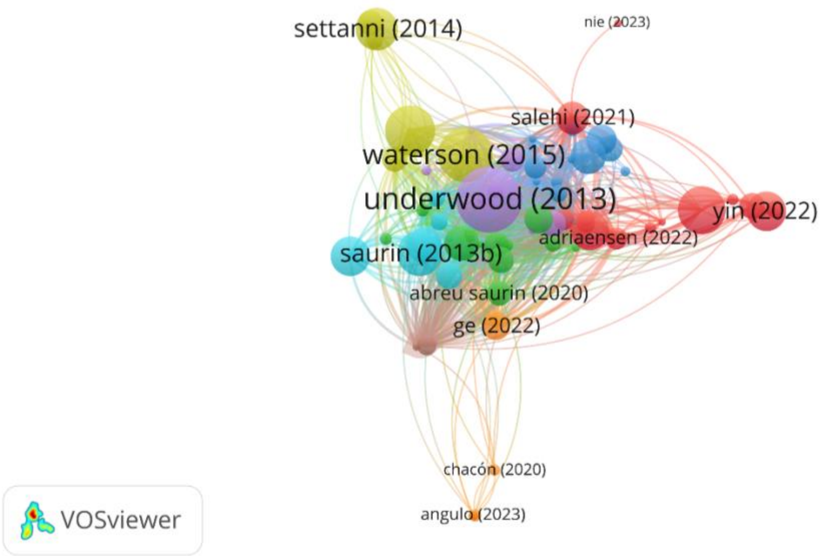

Figure 10: Map of bibliographic coupling of documents

In our analysis of “Co-citation of journal”, we applied a threshold of at least 20 citations per journal. This resulted in the identification of 19 journals that were grouped into four clusters, with a total of 107 links and a total link strength of 6,728. A network map for “Co-citation of journal” is presented in Figure 11. Among the 19 journals, the top three in terms of both citations received and total link strength were: (1) Safety Science (#citations=156, total link strength=2,684), (2) Reliability Engineering & System Safety (#citations=80, total link strength=1,402), and (3) Ergonomics (#citations=99, total link strength=1,578). It is worth noting that “safety science” and “saf. sci.” refer to the same journal, as do “reliability engineering & syt” and “reliab eng syst saf.” This is clear from the network map, which shows records with a single expression in the Scopus database. Furthermore, these journals are indexed using the SCIE index.

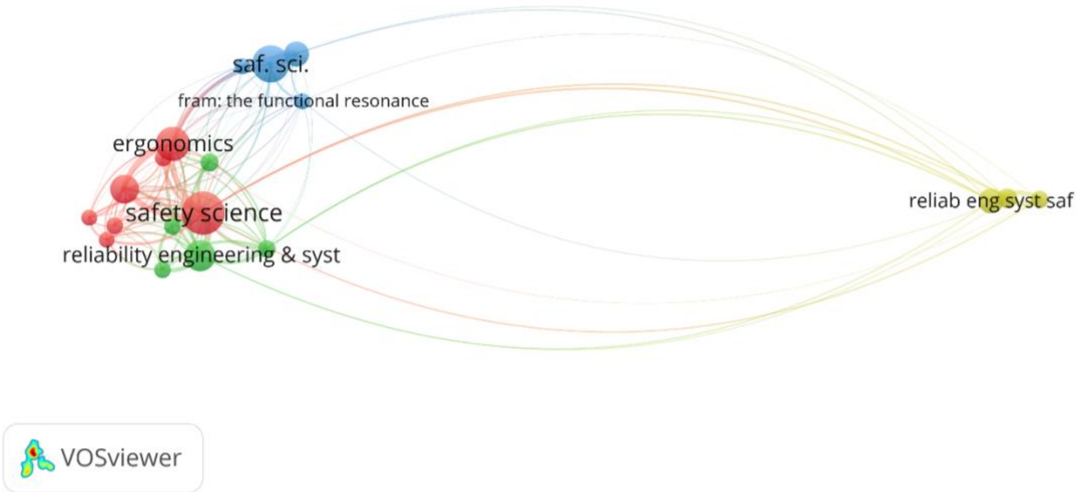

Figure 11: Map of co-citation analysis for journals

3. Conclusion

This study aimed to provide a comprehensive perspective for researchers by utilizing quantitative data on publications related to FRAM in the manufacturing industry from 2013 to 2023. Specifically, the study analyzed publications in the Scopus database and found that a significant number of them were published in the reputable journal, Safety Science. Tarcisio Abreu Saurin and Eric Hollnagel are prominent authors in this field. The study also identified Brazil, China, and Italy as the countries with the highest number of publications in this domain.

For future research, it is suggested that researchers consider studies related to keywords such as FRAM, sociotechnical systems, and resilience engineering to identify research gaps. However, the study's analysis was limited to the Scopus database, and it is recommended that future studies utilize the Web of Science (WOS) and Google Scholar databases to reassess the consistency of the network map. This is due to the abbreviations and full names of the journals where publications are produced, which may result in incomplete data. Additionally, the inability to access index information for publication types through the Scopus database interface is another limitation to be considered.

Conflicts of Interest

The author declares no conflict of interest.

References

[1]. Carré, H., "NACE Rev. 2, Statistical classification of economic activities in the European Community". General and regional statistics. p.44, 2008.

[2]. Tanyaş, M., & Baskak, M., "Üretim Planlama ve Kontrol. İrfan Yayıncılık". p.25, 2015.

[3]. Clark, D. P., Lima, L. R., & Sawyer, W. C., "Stages of diversification in high performing Asian economies". Journal of Economic Studies, 44(6): 1017-1029, 2017.

[4]. Haraguchi, N., Cheng, C. F. C., & Smeets, E., "The importance of manufacturing in economic development: has this changed?". World Development, 93: 293-315, 2017.

[5]. Özel, S., & Öztemel, E., "İşletmelerde Teknoloji Yönetimi ve Yetkinlik Bazlı Değerlendirme". Çanakkale Onsekiz Mart Üniversitesi Yönetim Bilimleri Dergisi, 16(31): 409-425, 2018.

[6]. Novotná, M., Volek, T., Rost, M., & Vrchota, J., "Impact of technology investment on firm's production efficiency factor in manufacturing". Journal of Business Economics and Management, 22(1): 135-155, 2021.

[7]. Bosman, L., Hartman, N., & Sutherland, J., "How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies". Journal of Manufacturing Technology Management, 31(5): 1117-1141, 2020.

[8]. Albery, S., Borys, D., & Tepe, S., "Advantages for risk assessment: Evaluating learnings from question sets inspired by the FRAM and the risk matrix in a manufacturing environment". Safety science, 89: 180-189, 2016.

[9]. Zheng, Z., Tian, J., & Zhao, T., "Refining operation guidelines with model-checking-aided FRAM to improve manufacturing processes: a case study for aeroengine blade forging". Cognition, Technology & Work, 18: 777-791, 2016.

[10]. Mutlu, N., Selim, S., & Altuntaş, S., "A multinomial logit model based approach to find patterns among occupational accidents in Turkish manufacturing systems". Journal of the Faculty of Engineering and Architecture of Gazi University, 39(2): 1049-1066, 2024.

[11]. Mutlu, N. G., Altuntas, S., & Dereli, T., "The evaluation of occupational accident with sequential pattern mining". Safety Science, 166: 106212, 2023.

[12]. Mutlu, N. G., & Altuntas, S., "Assessment of occupational risks In Turkish manufacturing systems with data-driven models". Journal of Manufacturing Systems, 53: 169-182, 2019.

[13]. Paguay, M., Febres, J. D., & Valarezo, E., "Occupational Accidents in Ecuador: An Approach from the Construction and Manufacturing Industries". Sustainability, 15(16): 12661, 2023.

[14]. Kee, D., "Characteristics of Work-Related Musculoskeletal Disorders in Korea". International Journal of Environmental Research and Public Health, 20(2): 1024, 2023.

[15]. SSI annual statistical report, 2013-2021. https://www.sgk.gov.tr/Istatistik/Yillik/fcd5e59b-6af9-4d90-a451-ee7500eb1cb4/. Access date: 6 Feb 2024.

[16]. Eurostat annual statistical report, 2013-2021. https://ec.europa.eu/eurostat/databrowser/view/hsw_n2_02__custom_9705352/default/table?lang=en. Access date: 6 Feb 2024.

[17]. Hollnagel, E., "Safety-I and safety-II: the past and future of safety management". CRC press. p.62, 127, 2014.

[18]. Hollnagel, E., "FRAM: the functional resonance analysis method: modelling complex socio-technical systems". Crc Press, 2012.

[19]. Riccardo, P., Gianluca, D. P., Giulio, D. G., & Francesco, C., "FRAM for systemic accident analysis: a matrix representation of functional resonance". International journal of reliability, quality and safety engineering, 25(01): 1850001, 2018.

[20]. Lee, J., & Chung, H., "A new methodology for accident analysis with human and system interaction based on FRAM:

Case studies in maritime domain”. Safety science, 109: 57-66, 2018.

[21]. Patriarca, R., Di Gravio, G., Woltjer, R., Costantino, F., Praetorius, G., Ferreira, P., & Hollnagel, E., “Framing the FRAM: A literature review on the functional resonance analysis method”. Safety Science, 129: 104827, 2020.

[22]. McGill, A., Smith, D., McCloskey, R., Morris, P., Goudreau, A., & Veitch, B., “The functional resonance analysis method as a health care research methodology: A Scoping review”. JBI Evidence Synthesis, 20(4): 1074-1097, 2022.

[23]. Salehi, V., Veitch, B., & Smith, D., “Modeling complex socio-technical systems using the FRAM: A literature review”. Human factors and ergonomics in manufacturing & service industries, 31(1): 118-142, 2021.

[24]. Ramkumar, B., Harish, V., Renuka, S. D., & Srinivasaiah, R., “Lean Manufacturing: A Bibliometric Analysis, 1970-2020”. Journal of Scientometric Research, 10(1): 63-73, 2021.

[25]. Blanco-Mesa, F., Merigó, J. M., & Gil-Lafuente, A. M., “Fuzzy decision making: A bibliometric-based review”. Journal of Intelligent & Fuzzy Systems, 32(3): 2033-2050, 2017.

[26]. Ivanov, D., Tang, C. S., Dolgui, A., Battini, D., & Das, A., “Researchers' perspectives on Industry 4.0: multi-disciplinary analysis and opportunities for operations management”. International Journal of Production Research, 59(7): 2055-2078, 2021.