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Resilience assessment and management

A review on contributions on process safety and environmental protection

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Resilience assessment and management: A review on contributions on process safety and environmental protection

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ABSTRACT

Resilience assessment and management of technical systems have been increasingly important as the current applications in the process industries are becoming more complex. Several review papers on resilience management methods and applications have been published by researchers from different aspects. However, none of them put the focus on bibliometric analysis of the relevant research works especially those in the process industries. This study pays attention to system resilience assessment and management, by reviewing sources of relevant publications, collaboration of institutions and authors, and development trends. In addition, the development of resilience engineering and management is further investigated through analyzing the most influential and relevant journals of process safety and environmental protection. This review provides valuable information regarding knowledge structure, evolution and influential publications, and high-level insights for future research.

1. Introduction

In the process industries, modern technical systems are integrating more computational, communicational, and physical elements, with inter-dependences and many functional redundancies, and they are expected to be unaffected or little affected by single failure or hazardous events. The traditionally bimodal assumption (only considering functional and failed states) is not sufficient for the comprehensive analysis of complex system behaviors. The concept of resilience is thus being accepted by more researchers in process safety and other fields, since it considers all behaviors of a system after a hazardous event, including shock absorption, recovery, and adaption.

In recent years, the definition of resilience has been explored by many scholars from different perspectives. For example, resilience is defined as the ability of a system to absorb changes or disturbances (Pawar et al., 2021), and the source can be traced to its use on ecology (Holling, 1973a) and medical research (Bergström et al., 2015). Based on this understanding, Woods et al (Woods, 2015). developed the concept of resilience as the opposite of brittleness, as well as the ability of a system to adapt to future surprises as conditions evolve (also in (Yarveisy et al., 2020)). Haimeis (Haimes, 2009) pointed out that resilience is essential for safety management which can help decision-makers dealing with various scenarios. All in all, resilience refers to a theoretical tool focusing on the transformation probability of a system from incidents to accidents. In the field of process safety and environmental protection, considering the nature of stochastic and time-variable, (Castillo-Borja et al., 2017) reckoned that the factors, e.g., avoiding failure, pro-active, losses and response after failure, should be taken into account while discussing the definition of resilience. In this study, resilience is expected to be described as the capacity of a process/environment system to prevent the negative impact while suffering from the external disruption and to recover comprehensively considering the response time, operation costs and possibility. To improve the system performance before, during, and after any disruptive event, more efforts are needed for normalization of functionality in a system (Hollnagel et al., 2006), in the phases of preparedness, response, and recovery

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stage (Shirali et al., 2016a). For example, after a disruptive event occurs, responses are required to mitigate negative effects and to recover system performance. The system is adjusted with the lessons learned, while continuous monitoring and prognostics are necessary to smoothly run the system and to prepare it for future events. By efficiently anticipating, learning, monitoring, and responding, a safe working and manufacturing environment can be then established for complex engineering systems, particularly adaptive systems, and lower the environmental inherent hazards associated with system operation.

Here we use the terminology of resilience management, rather than resilience engineering like what many studies use, because in our context, resilience management is more representative, referring to a framework of activities before and after a disruptive event occurs, including planning, resilience quantification and assessment, engineering and operational improvement, and managerial and organizational optimization. In fact, a couple of reviews have been performed in this field. For example, Righi et al (Righi et al., 2015). have conducted a review and summarized six research areas of resilience management, including theories, classification, safety management tools, risk assessment, accident analysis and training. Patriarca et al (Patriarca et al., 2018). have used factor analysis and multi-dimensional scaling to extract five aspects from a resilient system, i.e., demand, modelling, definition, response, and improvisation. Additionally, Hickford et al (Hickford et al., 2018). made an overview of the various resilience engineering approaches and assessment metrics in infrastructure systems. Ellis et al (Ellis et al., 2019). have conducted a scoping review and bibliometric analysis on the patterns of resilience in the healthcare sector. Pawar et al (Pawar et al., 2021). have presented key research areas and approaches of resilience management in the process industries. Mishra et al (Mishra et al., 2021). have reviewed the planning, operational, and planning-operational aspects for resilience of active distribution systems in electric power systems.

Currently, one of key challenges existing literature studies on resilience management is that they are implemented by the researchers with various backgrounds, resulting in the difference while understanding the term. Such difficulties are further expanded by the lack of a consistent definition and terminologies. A bibliometric overview on resilience assessment and the following management approaches will be useful to remove the barriers between different domains and understand the knowledge status and evolution, especially in the field of process safety and environmental protection. An earlier bibliometric analysis for the literature between 1985 and 2014 had been performed by Xue et al (Xue et al., 2018). However, much research regarding resilience management have been published in recent years, thus, an updated analysis is necessary for reflecting the recent development in this field.

It should be noted that resilience assessment is regarded as the core in the whole management framework, since it is the foundation of following works. Thus, the review on the methods of resilience assessment is emphasized in this study. To investigate the development of resilience assessment and management, this study conducts the bibliometric analysis based on Citespace, Vosviewer and R, analyzing the temporal and geographic trends, collaborations, and citation relationship etc.

The remainder of this paper is organized as follows: Section 2 presents an overview of resilience system analysis. Section 3 explicitly clarifies the statistics characteristics from the perspective of outputs, collaboration, and intellectual basis, while Section 4 and Section 5 analyze the methods regarding resilience assessment and the development level of resilience analysis in the specific journals, respectively. Section 6 highlighted the difference of current research comparing to previous review and discussed the limitations and value simultaneously. Section 7 concludes the review and suggests future research directions. The technical routine of this review is illustrated in Fig. 1.

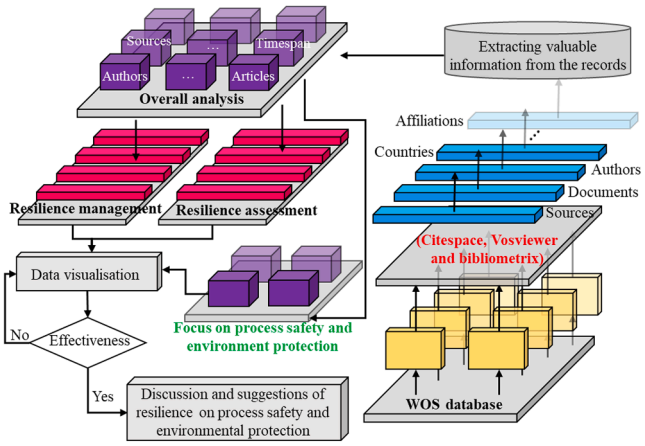


Fig. 1. Flowchart of the review on resilience assessment and management.

2. Data collection and overview

The data was obtained from *Clarivate Web of Science Core Collection*, from which five sub-databases were selected, including *SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH, A&HCI,* and *ESCI.*[1] The five sub-databases can effectively cover most of the peer-reviewed works in resilience engineering while also ensuring the quality of publications to a certain extent. A topic search strategy with search term "resilience engineering" OR "resilience assessment" OR "resilience quantification" OR "resilience management" OR "quantitative resilience assessment" OR "resilience network" was applied to the data collection. To obtain all data related to resilience analysis in the database before 31–08–2022, the timespan was set as from 01 to 01–1945 to 31–08–2022. Finally, in total 1691 publications were extracted from the databases. 1691 articles were selected based on five sub-databases, screened by timespan and search terms. Bibliographic data of the selected documents including authors, abstracts and citations are exported and further analyzed.

An overview of the resilience analysis is given in Table 1. The publications are collected from 764 sources and include 4455 keywords. The 1691 papers totally received 5966 citations with 13.71 average citations per document. Even though resilience analysis has a relatively short history, there appears 4706 authors in the dataset, indicating a wide interest in the concepts and approaches. Of these documents, 115 are single authored, while most documents are made by multiple authors. The collaboration index (Elango and Rajendran, 2012), defined as a ratio of Authors of multi-authored documents by multi-authored documents, is 2.94.

In this study, the review regarding resilience management refers to three theorical tools, i.e., Vosviewer (Eck and Waltman, 2020), Citespace (Chen, 2006, 2004) and Biblimetrics (Aria and Cuccurullo, 2017). There, the Citespace tool is used to implement the keywords analysis with the datasets obtained through the mentioned search strategy, as shown in Fig. 2. The size and link of nodes corresponds to the frequency and connection of keywords, respectively. Keywords are often extracted from the research topic, that is, keywords analysis can describe the potential connections between different topics and further explore the development level of subjects. In Fig. 2, the high frequency words, e.g., "resilience engineering", "management", "resilience assessment" and "sustainability" indicate the issues, including earth science and environmental protection, process optimization and safety analysis have gained a large volume of attentions from scientific community, and

[1] *Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index – Science (CPCI-S), Conference Proceedings Citation Index – Social Science & Humanities (CPCI-SSH), Emerging Sources Citation Index (ESCI)*

Table 1
Main information of the resilience research.

Description	Results	Description	Results
Timespan	1997–2022	Sources	764
Average years from publication	3.62	References	59091
Average citations per documents	15.15	Documents	1691
Average citations per year per doc	0.583	Article	1160
Author's Keywords (DE)	4455	Article; early access	44
Authors	4706	Article; proceedings paper	6
Annual Growth Rat%	24.03	Correction	6
Authors of single-authored documents	115	Editorial material	20
Authors of multi-authored documents	4591	Meeting abstract	5
Single-authored documents	127	News item	1
Documents per Author	0.359	Proceedings paper	329
Authors per Document	2.78	Review	113
Co-Authors per Document	3.8	Review; book chapter	1
Collaboration Index	2.94	Review; early access	3

Note: Collaboration index $= \frac{\text{Authors of Muti} - \text{authored documents}}{\text{Muti} - \text{authored documents}}$

Fig. 2. eywords analysis for resilience management.

much research have been published in this field.

Research outputs are considered as the significant indicator for a subject/field to measure the development level of resilience management, especially for process plant and industrial system resilience. As is shown in Fig. 3, a large proportion of publication types in resilience analysis is article, which is increased from 5 to 273 during a period from 2010 to 2021, while a similar development trend was seen on review publications. Accumulative publications have seen a significant increase with exponential characteristics in the recent 15 years, indicating resilience management has got a lot of attention, which in turn reflects

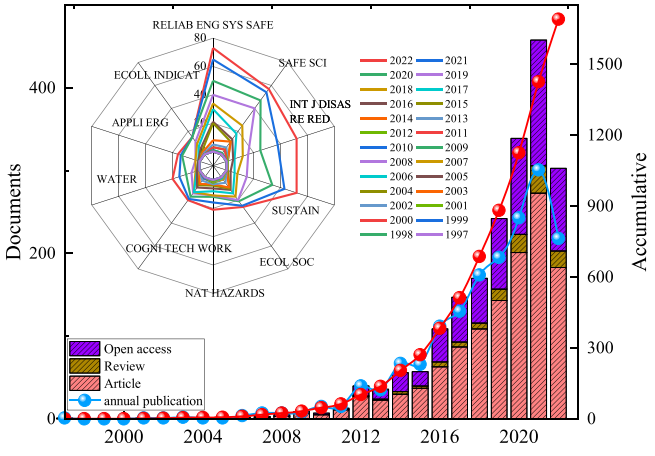


Fig. 3. Annual documents regarding resilience research from 1997 to 2021.

the great demand on solutions for resilience issues. Additionally, the most relevant journals contributing to these documents and its annual publications associated with the topics are counted. It is clear that the role of the top four journals including "RELIAB ENG SYS SAFE", "SAFE SCI", "INT J DISAS RE RED" and "SUSTAIN" are considerably important, making it more efficient for scholars to collect valuable information with respect to the research of process safety and environmental protection.

3. Statistics analysis for resilience management

3.1. Journal outputs

Highly productive and influential journals are the main knowledge sources for resilience management research, it can be considered as an important indicator to display the knowledge distribution. In Fig. 4, it is seen that *Safety Science* (Number of Publications (NP) = 49) is the most productive journal in resilience management, followed by the *Reliability Engineering & System Safety* (35), *Cognition, Technology & Work* (18), *Applied Ergonomics* (14), *Work: -A Journal of Prevention Assessment & Rehabilitation* (12) and *Journal of Loss Prevention in the Process Industries* (11). The publications regarding resilience management were first published in 2006, while it saw a sharply increase since 2009.

3.2. Collaboration analysis

3.2.1. Countries/regions outputs and collaboration

The most productive countries/regions and collaborations of them are visualized in Fig. 5 and Table 2. Iran and France have the most frequent communication regarding resilience management with frequency equals to 8, corresponding to the width of links between them. The collaborations among Canada, Italy, the UK, the USA, and Netherland are also frequent, which is 4.

For resilience management, many countries/regions carried out their research in this field. The United States is the most productive country with 79 publications, followed by Iran (61), Brazil (48), United Kingdom (41), Australia (36) and Italy (35). The collaboration network density between countries/regions is considerably low, indicating the international collaborations in this field are not enough. The collaborations are established between Iran and France, Iran and Canada, Brazil and the United States of America, Brazil and Australia, Italy and United Kingdom, and Italy and France.

3.2.2. Institutions outputs and collaboration

Top 10 highly productive institutions contributing the most publications on resilience management are listed in Table 3. The most productive institution is University of Tehran (Iran) with 44 publications. Meanwhile, the institutions associated with the collaboration networks are visualized in Fig. 6, the size of labels and nodes are used to show the number of publications, while the color of nodes is connected to the subnetwork. Links between each node reflect the collaboration relations. Some of highly productive institutions are distributed in different communities. The institutions including Univ Tehran (Iran), Univ Fed Rio De Janeiro (Brazil), Univ Fed Rio Grande Do Sul (Brazil), Sapienza Univ Rome (Italy), Norwegian Univ Sci & Technol (Norway), and Texas A&M Univ (United States) are identified as the most productive ones. The average publication year is an efficient indicator to analyze the temporal evolution of an institution, as shown in Fig. 3. It is concluded that Sapienza Univ Rome (Italy) is the most recently active institution with an average publication year of 2018.88, followed by Griffith Univ (Australia), Georgia Inst Technol (USA), Univ Tehran (Iran) and Ahvaz Jundishapur Univ Med Sci (Iran).

3.2.3. Authors outputs and collaboration

The outputs and collaboration networks of authors are visualized vividly in Fig. 7. The dark blue and red nodes are corresponds to the previous and latest studies, respectively, reflecting the dynamic

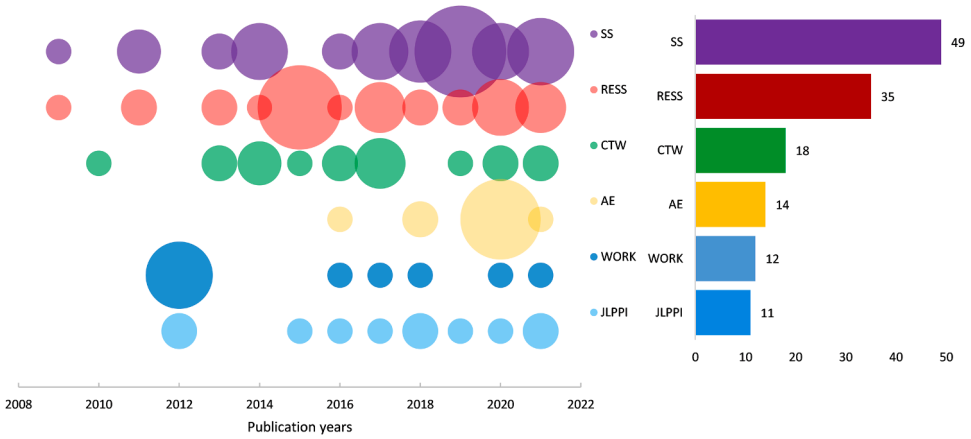


Fig. 4. Journals distribution of resilience management (NP>10). Note: SS=Safety Science, RESS=Reliability Engineering & System Safety, CTW=Cognition Technology & Work, WORK=Work-A Journal of Prevention Assessment & Rehabilitation, JLPPI=Journal of Loss Prevention in The Process Industries.

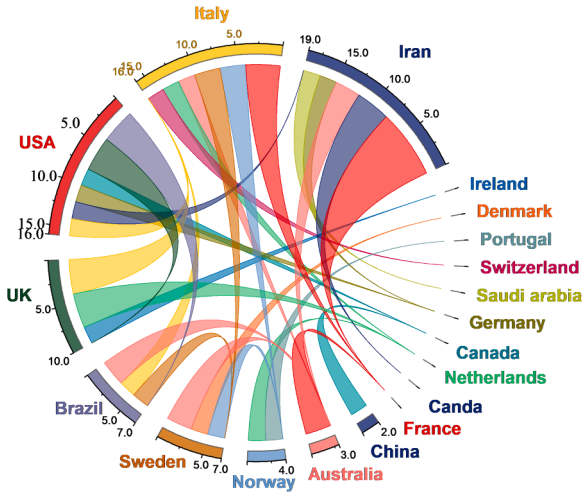


Fig. 5. Collaboration networks for different countries (frequency = 1 was removed).

Table 2
High productive countries/regions for resilience management.

No.	Countries/regions	NP	TC	APY	AC
1	United States	79	1604	2016.58	20.30
2	Iran	61	732	2017.54	12.00
3	Brazil	48	855	2015.45	17.81
4	United Kingdom	41	507	2016.63	12.37
5	Australia	36	486	2018.12	13.50
6	Italy	35	557	2017.94	15.91
7	Norway	32	385	2015.81	12.03
8	France	27	218	2017.04	8.07
9	Sweden	25	637	2016.44	25.48
10	Netherlands	24	272	2016.79	11.33

Notes: These results are obtained by VOSviewer software. NP = number of publications; TC = total citations; AC = average citations per paper; APY = average publication year; Degree = number of collaborating countries/regions of a node in the network.

influence of individual scholar, through which the active researchers and achievements are highlighted. Azadeh A (Iran) is the most productive author in the collaboration networks (Table 4), who published 30 papers and cooperated with 42 different authors during a period from 2014 to 2019. "data envelopment analysis" and 'fuzzy' are most widely-used methods in his research (Azadeh et al., 2014a, 2016a, 2015, 2016a, 2014b, 2016b, 2016c). In his networks, Salehi V (CAP=13), Yazdanparast R (CAP=7), Zarrin M (CAP=5) and Haghighi SM (CAP=5) are the authors who has at least 5 co-authored publications (CAP). The publications of Salehi V (Iran) and Saurin TA (Brazil) see a similar evolution trend, climbing to the peak around 2016 and 2017.

Saurin TA is the second-most productive author with 17 publications. His publications are mainly from 2009 to 2021 (4 published in 2020 and 3 published in 2021), including, electricity distributor (Wachs et al., 2012; Saurin and Carim, 2011), grid electricians (Saurin et al., 2014), air taxi carriers (Saurin et al., 2013), healthcare (Rosso and

Table 3
Top 10 high productive institutions in resilience management.

No.	Institutions	NP	TC	APY	AC
1	Univ Tehran	44	626	2017.11	14.23
2	Univ Fed Rio De Janeiro	17	146	2015.35	8.59
3	Univ Fed Rio Grande Do Sul	16	452	2016.00	28.25
4	Sapienza Univ Rome	16	311	2018.88	19.44
5	Norwegian Univ Sci & Technol	16	101	2015.38	6.31
6	Texas A&M Univ	10	239	2016.70	23.90
7	Griffith Univ	10	192	2018.40	19.20

Notes: NP = number of publications; TC = total citations; AC = average citations per paper; APY = average publication year.

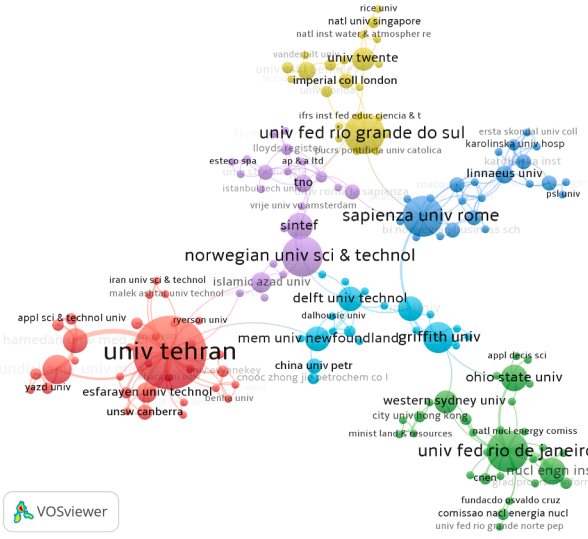


Fig. 6. Core institutions collaboration network of resilience management.

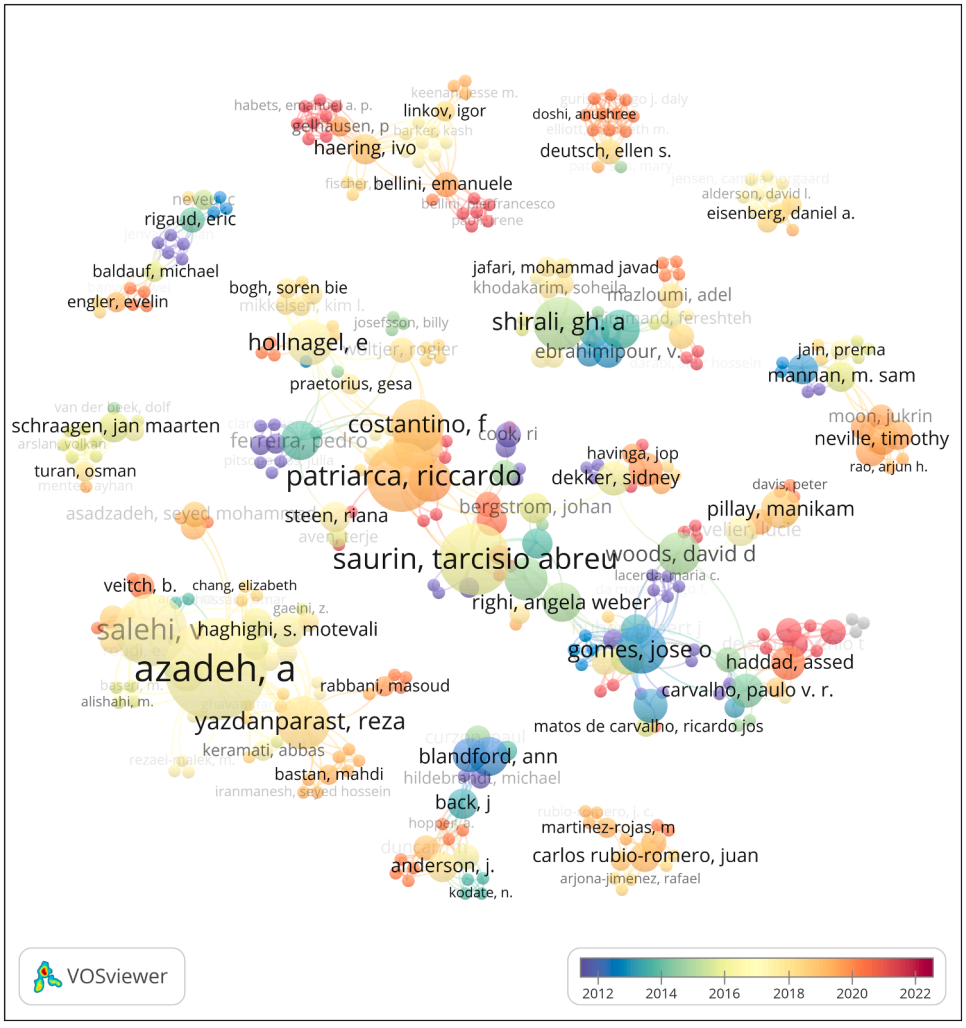


Fig. 7. Average publication years of each author in the collaboration network.

Table 4
Top 10 most-productive authors at least with 5 papers in resilience management.

Authors	Mainly affiliated institutions	NP	TC	APY	AC
Azadeh, A	Univ Tehran	30	425	2016.70	14.17
Salehi, V	Univ Tehran	17	293	2016.88	17.24
Saurin, Tarcisio Abreu	Univ Fed Rio Grande do Sul	17	453	2016.29	26.65
Patriarca, Riccardo	Sapienza Univ Rome	16	374	2018.81	23.38
Shirali, Gh. A	Ahvaz Jundishapur Univ Med Sci	10	257	2015.30	25.70
Yazdanparast, Reza	Univ Tehran	10	63	2017.80	6.30
Costantino, F	Sapienza Univ Rome	10	318	2018.50	31.80
Di Gravio, Giulio	Sapienza Univ Rome	9	296	2018.56	32.89
Gomes, Jose O	Univ Fed Rio de Janeiro	9	128	2013.22	14.22
Hollnagel, E	Univ Southern Denmark	8	224	2016.88	28.00

Notes: NP = number of publications; TC = total citations; AC = average citations per paper; APY = average publication year.

Saurin, 2018) and emergency departments (Wachs et al., 2016) etc. Among his publications, there are two papers received over 80 citations (Righi et al., 2015; Costella et al., 2009), showing a great contribution on resilience research. The paper '*A systematic literature review of resilience engineering: Research areas and a research agenda proposal*' (Righi et al., 2015) has been cited 150 times, and '*A method for assessing health and safety management systems from the resilience engineering perspective*' (Costella et al., 2009) has received 116 citations. Another representative author is Patriarca R (Italy), who has published 16 papers and cooperated with 21 authors. Costantino F and Di Gravio G are the main collaborators of Patriarca R. For the former, the publication "*Resilience engineering: Current status of the research and future challenges*" (Patriarca et al., 2018) has been cited 120 times, and his main research includes complexity, safety management and the FRAM method (Patriarca et al., 2017a, 2017a; Patriarca and Bergstrom, 2017; Gattola et al., 2018; Falegnami et al., 2022).

Among the authors in the largest community, Gomes JO is from Univ Fed Rio de Janeiro (Brazil), and he has published 9 papers in RE research from 2006 to 2021. The topics of his papers focus on resilience indicators (de Carvalho et al., 2012; Huber et al., 2012), system resilience, and brittleness (Dolif et al., 2013; Gomes et al., 2009). The highest cited paper is '*Resilience and brittleness in the offshore helicopter transportation system: The identification of constraints and sacrifice decisions in pilots'* (Gomes et al., 2009) with 54 citations by the end of 2021. By comparison, Shirali GA, whose publications mainly concentrated on the period 2012–2018, carrying out resilience research with different backgrounds using quantitation-based methods, e.g., process industry, drilling company, petrochemical plant, chemical plant, and hospital (Shirali et al., 2018, 2016b, 2016a, 2012a, 2016b, 2012b; Nodoushan et al., 2017; Jafari et al., 2018, 2013; Arassi et al., 2015). One of his publications entitled "*A new method for quantitative assessment of resilience engineering by PCA and NT approach: A case study in a process industry*" received 81 citations. As one of the pioneers in the field of resilience, Hollnagel E

published 8 papers with 18 collaborators during a period from 2013 to 2020, and his research topic includes healthcare, build environment, and nuclear disasters (Raben et al., 2018, 2017; Hollnagel and Fujita, 2013; Hollnagel, 2014a). It is noted that Hollnagel E has published serval books on resilience management, whereas he has been comparatively less active in terms of the number of publications on journals and conferences.

3.3. Intellectual basis

Cited references are considered as an important information source to mine valuable information and comprehensively understand the research. In this work, we extract the cited sources, cited authors and cited references, to explore the intellectual basis of resilience management.

3.3.1. Sources co-citation analysis

When documents from two (or more) sources are simultaneously cited by a third document, the two (or more) sources are considered to have a co-citation relationship (Li et al., 2021). The sources co-citation network cluster of resilience engineering is shown in Fig. 8, where the size of nodes and fonts represents the number of citation sources (e.g., journals, books, or reports). The higher the frequency of co-citation of two documents, the thicker the links between the two associated nodes.

In Fig. 8 and Table 5, four clusters are obtained to provide insight in the most attractive topics within the field. It is observed that "Safety and human work related", "Health care related" and "Process safety and hazard" are the three majors clusters. *Safety Science* and *Reliability Engineering and System Safety* are the main journals contributing to 1245 citations and 771 citations, respectively. As for the co-citation analysis, *Safety Science* has the strongest link strength (34646), followed by *Reliability Engineering and System Safety* (24389) and *Resilience Engineering - Concepts and Precepts* (12589). Furthermore, *Safety Science* and *Reliability Engineering and System Safety* have the closest relationship with link strength 6439, indicating these two journals are the essential sources for our resilience research.

Table 5
Top 10 highly cited sources in each cluster of resilience management.

Cluster No.	Top 10 highly cited sources in each cluster
# 1	Resilience Engineering - Concepts and Precepts (508), Cognition, Technology & Work (253), Resilience Engineering in Practice (236), Resilience Engineering Perspectives (166), Resilient Health Care (135), Human Factors (95), Quality & Safety in Health Care (88), Journal Contingencies and Crisis Management (82), FRAM (80), Administrative Science Quarterly (69).
# 2	Safety Science (1245), Reliability Engineering and System Safety (771), Journal of Loss Prevention in the Process Industries (319), Applied Ergonomics (210), Process Safety and Environmental Protection (153), Ergonomics (114), Process Safety Progress (72), Accident Analysis and Prevention (70), Journal of Construction Engineering Management (49), Work (49).
# 3	Risk Analysis (117), IEEE Systems Journal (63), Ecology and Society (58), Science (48), Global Environmental Change (46), Building Research & Information (40), Nature (39), Annual Review of Ecology, Evolution, and Systematics (33), Earthquake Spectra (32), Proceedings of the National Academy of Sciences of the United States of America (32).
#4	European Journal of Operational Research (98), Expert Systems with Applications (72), Journal of Cleaner Production (72), International Journal of Production Research (66), International Journal of Production Economics (49), Management Science (37), Energy Policy (35), International Journal of Advanced Manufacturing Technology (32), Journal of Operations Management (32), Computers & Industrial Engineering (31), Enterprise Information Systems (31), Omega-International Journal of Management Science (31).

3.3.2. Authors co-citation analysis

When documents from two (or more) authors are simultaneously

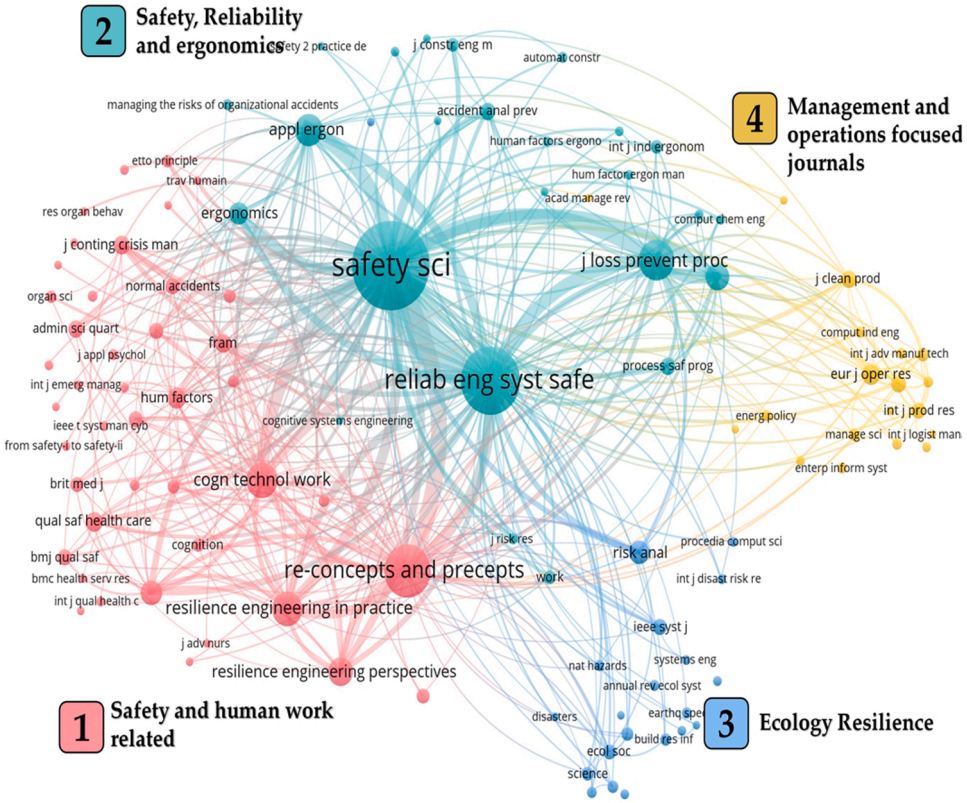


Fig. 8. Clusters of high cited sources in resilience management.

cited by a document from a third author, the two (or more) authors are considered to constitute a co-citation relationship (Li et al., 2021). In Fig. 9, the authors co-citation networks are clustered, highlighting the most highly cited authors and their relationships to other authors. Three clusters are denoted as "Resilience Engineering", "Practice of Resilience Engineering", and "Resilience Engineering connection with Safety Science". Co-citation relationships, corresponding to the thickness of the links, reflect the extent of overlap of research and interconnections. It is clear that Hollnagel E is the highly cited author with 957 citations, and the co-citation link strength over 15252, while the co-citation links of Woods DD and Dekker S are 8494 and 4921, respectively. Among these authors, Hollnagel E and Woods DD are frequently co-cited by other researchers with link strength 1748. (Tables 6 and 7).

3.3.3. *Documents co-citation analysis*

Co-citation relationship between documents is a link between two (or more) documents cited by the same document, and it clarifies the documents that are frequently cited simultaneously (Li et al., 2021). The clusters of documents are shown in Fig. 10, which are consistent with the previous analysis that the scholar Hollnagel E makes the most contribution in resilience management according to the number of co-citations and the application scope. Furthermore, the most influential documents shown in this figure are perfectly consistent with those that analyzed above.

The book entitled *Resilience Engineering Concepts and Precepts* (by Hollnagel E) is mostly cited with 142 citations. Besides, other books produced/cooperated by Hollnagel E are also widely recognized by scientific community, e.g., *Resilience Engineering in Practice* (74 Citations), *The Functional Resonance Analysis Method: Modelling Complex Socio-Technical Systems* (71 Citations). By comparison, the article entitled '*A Method for Assessing Health and Safety Management Systems from The Resilience Engineering Perspective*' (produced by Costella MF) has been cited 50 times, which is much less than the citations of aforementioned books. This phenomenon is mainly caused by the document length, knowledge coverage, depth of analysis, and emphasis. Books are often organized to accommodate more contents, putting more energy on fundamental knowledge, and cover a wider range of research fields. The book entitled *Resilience Engineering Concepts and Precepts* (Hollnagel E) has 123 links in total with the link strength 1090. The document has the closest relationship with aforementioned publication is the book *Normal Accidents: Living with High-Risk Technologies* (total link strength 33) produced by Perrow C in 1984/99 and the book *Resilience Engineering in Practice* (by Hollnagel E).

Table 6
Top 10 highly cited authors in each cluster of resilience management.

Cluster No.	Top 10 highly cited authors in each cluster
# 1 Resilience Engineering	Hollnagel, E (957), Woods, DD (435), Dekker, S (225), Leveson, N (179), Patriarca, R (156), Nemeth, Cp (84), Braithwaite, J (75), Lundberg, J (62), Aven, T (60), Wears, Rl (60).
# 2 Practice of RE	Azadeh, A (334), Shirali, Ga (133), Saurin, Ta (121), Wreathall, J (88), Costella, Mf (53), Carvalho, Pvr (46), Dinh, Ltt (43), Steen, R (41), Madni, Am (40), Gomes, Jo (37).
# 3 RE connection with Safety Science	Rasmussen, J (131), Weick, Ke (129), Reason, J (99), Perrow, C (79), Hale, Ar (78), Le Coze, Jc (51), Sutcliffe, Km (44), Hopkins, A (41), Roberts, Kh (37), La Porte, Tr (35).

4. Focus on resilience assessment

As the main part of resilience management, resilience assessment is beneficial from many different methods designed for different technical systems. The topic is set as "resilience assessment", a total of 954 records are identified for resilience analysis. The clusters and their labels are visualized in Fig. 11 while the number of clusters is set as 7. The labels are denoted as "extreme weather", "urban resilience", "family resilience", "reliability", "vulnerability assessment" and "resilience assessment". It seems that the connections between these labels are considerably weak. The variety of clusters mainly results from the wide application of resilience assessment and the multidiscipline search strategies. Each node corresponds to a keyword and its size represents the frequency, meanwhile, the links between the nodes are described by centrality. Top five centrality are {0.28, 0.13, 0.11, 0.11, 0.11}, corresponding to "climate change", "adaptation", "community", "hazard" and "management", respectively.

Cited author analysis is implemented to highlight the role of individuals and to analyze the connection of them. In Fig. 12, the size of nodes is determined by the intensity of citations, meanwhile, the frequency of authors and most influential scholars are counted in Table 8.

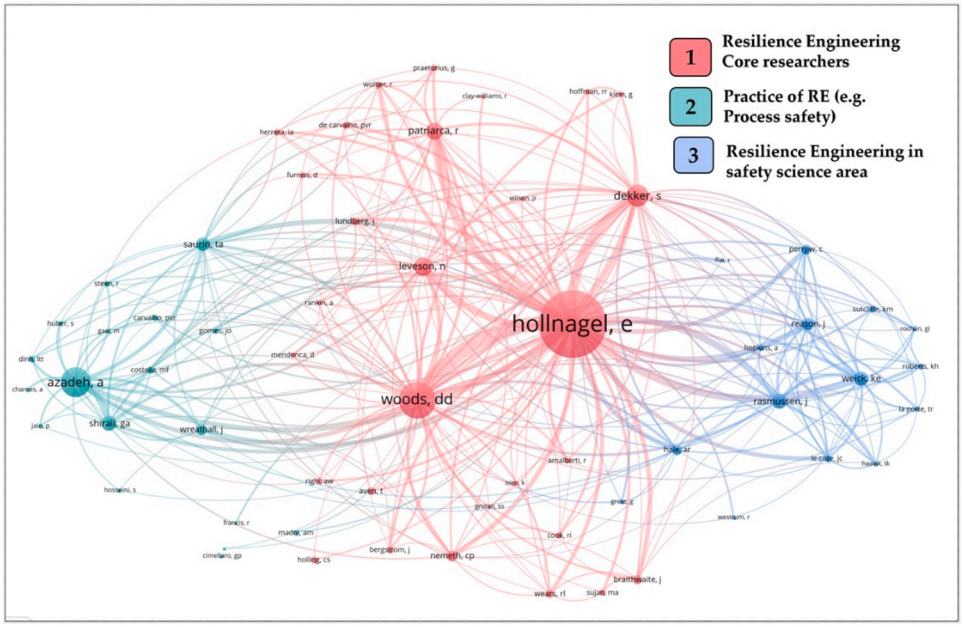


Fig. 9. Authors co-citation analysis of resilience management.

Table 7
Top 10 cited references in each cluster of resilience management research.

Cited Authors (first Authors)	Years	Source	Title	cluster	Citations
Hollnagel E (Hollnagel et al., 2006)	2006	*Resilience Engineering: Concepts and Precepts*	*Book*	1	231
Hollnagel E (Hollnagel et al., 2011)	2011	*Resilience Engineering in Practice*	*Book*	1	74
Perrow C (Perrow, 1984)	1984/99	*Normal Accidents: Living with High-Risk Technologies*	*Book*	1	55
Hollnagel E (Hollnagel, 2004)	2004	*Barriers and Accident Prevention*	*Book*	1	42
Rasmussen J (JensRasmussen, 1997)	1997	*Safety Science*	*Risk management in a dynamic society: a modelling problem*	1	42
Hollnagel E (Hollnagel and Woods, 2005)	2005	*Foundations of Cognitive Systems Engineering*	*Book*	1	40
Hollnagel E (Hollnagel, 2009)	2009	*The ETTO Principle: Efficiency-Thoroughness Trade-Off*	*Book*	1	38
Hollnagel E (Nemeth and Hollnagel, 2008; Hollnagel and Nemeth, 2009)	2008,2009	*Resilience Engineering Perspectives*	*Book*	1	37
Leveson N (Leveson, 2004)	2004	*Safety Science*	*A New Accident Model For Engineering Safer Systems*	1	35
Holling Cs (Holling, 1973b)	1973	*Annual Rev Ecol Syst*	*Book*	1	33
Wreathall J	2006	*Resilience Engineering: Concepts and Precepts* *Properties of Resilient Organizations: An Initial View*	*Book*	2	64
Costella M F (Costella and Saurin, 2009)	2009	*Safety Science*	*A method for assessing health and safety management systems from the resilience engineering perspective*	2	50
Dinh LTT (Dinh et al., 2012)	2012	*Journal of Loss Prevention in the Process Industries*	*Resilience engineering of industrial processes: Principles and contributing factors*	2	42
Azadeh A (Azadeh et al., 2014a)	2014	*Process Safety and Environmental Protection*	*Performance evaluation of integrated resilience engineering factors by data envelopment analysis: The case of a petrochemical plant*	2	40
Saurin T A (Saurin and Carim, 2011)	2011	*Safety Science*	*Evaluation and improvement of a method for assessing HSMS from the resilience engineering perspective: A case study of an electricity distributor*	2	38
Shirali GA (Shirali et al., 2013)	2013	*Reliability Engineering and System Safety*	*A new method for quantitative assessment of resilience engineering by PCA and NT approach: A case study in a process industry*	2	38
Steen R (Steen and Aven, 2011)	2011	*Safety Science*	*A risk perspective suitable for resilience engineering*	2	37
Huber S (Huber et al., 2009)	2009	*Process Safety Progress*	*Learning From Organizational Incidents: Resilience Engineering for High-Risk Process Environments*	2	31
Leveson N	2007	*Resilience Engineering: Concepts and Precepts*	*Book*	2	31
Azadeh A	2014	*Safety Science*	*Assessment of resilience engineering factors in high-risk environments by fuzzy cognitive maps: A petrochemical plant*	2	30
Hollnagel E (Erik, 2012)	2012	*FRAM: the functional resonance analysis method: modelling complex socio-technical systems*	*Book*	3	71
Woods DD (Woods, 2015)	2015	*Reliability Engineering and System Safety*	*Four concepts for resilience and the implications for the future of resilience engineering*	3	59
Hollnagel E (Hollnagel, 2014b)	2014	*From Safety-I to Safety-II: A White Paper*	*Book*	3	42
Righi A W (Righi et al., 2015)	2015	*Reliability Engineering and System Safety*	*A systematic literature review of resilience engineering: Research areas and a research agenda proposal*	3	38
De Carvalho PVR (de Carvalho, 2011)	2011	*Reliability Engineering and System Safety*	*The use of Functional Resonance Analysis Method (FRAM) in a mid-air collision to understand some characteristics of the air traffic management system resilience*	3	33
Bergstrom J (Bergstrom et al., 2015)	2015	*Reliability Engineering and System Safety*	*On the rationale of resilience in the domain of safety: A literature review*	3	31
Patriarca R (Patriarca et al., 2018)	2018	*Safety Science*	*Resilience engineering: Current status of the research and future challenges*	3	31
Clay-Williams R (Clay-Williams et al., 2015)	2015	*Implementation Science*	*Where the rubber meets the road: using FRAM to align work-as-imagined with work-as-done when implementing clinical guidelines*	3	29
Patriarca R (Patriarca et al., 2017a)	2017	*Safety Science*	*A Monte Carlo evolution of the Functional Resonance Analysis Method (FRAM) to assess performance variability in complex systems*	3	25
Patriarca R (Patriarca et al., 2017b)	2017	*Reliability Engineering and System Safety*	*Defining the functional resonance analysis space: Combining Abstraction Hierarchy and FRAM*	3	20

The former is obtained through analyzing the size of nodes directly, while the latter is obtained through calculating the centrality. For example, Hosseini S et al. reviewed the definition of resilience and summarized the quantitative and qualitative methods for resilience measurement (Hosseini et al., 2016), as shown in Fig. 13. it explicitly illustrates the current research conditions from different domains. In Table 8, it can be seen that Meerow S, Frazier TG, Ayyub BM, Asadzadeh A and Aldunce P are the most influential scholars in this field, whose publications significantly expand available research.

Resilience curve can describe the performance change of a system before and after a disruptive event. The ratio of system performance before and after the disruptive events can be considered as an efficient metrics (Yodo and Wang, 2016). Based on the literature study, the resilience assessment methods can be generally categorized into qualitative assessment and quantitative assessment, the latter can be further divided into semi-quantitative, deterministic, and probabilistic methods

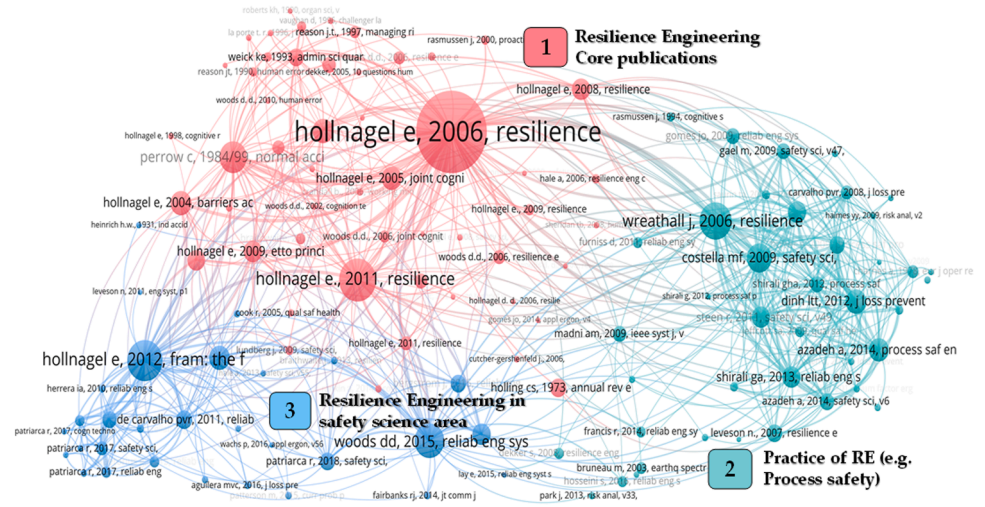


Fig. 10. Documents co-citation analysis of resilience management (the label indicates the first author and the publication year, with the sublabel indicating the source of the document).

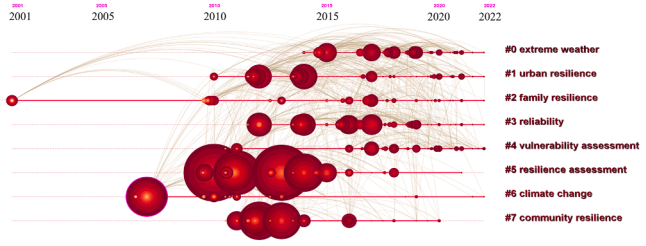


Fig. 11. Timeline for keywords clusters.

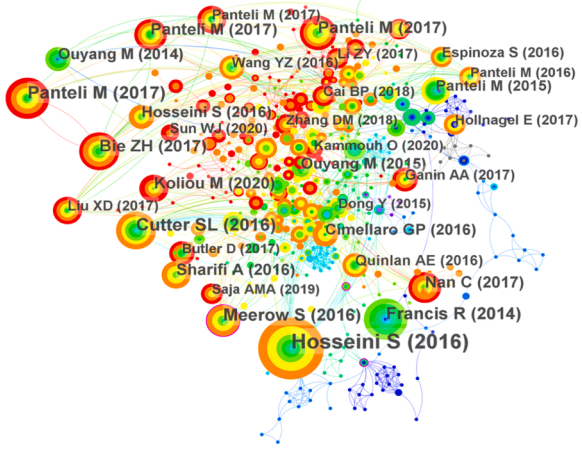


Fig. 12. Cited author analysis for resilience assessment.

(Gasser et al., 2021). For the process industry, questionnaire/survey is reasonable (Pawar et al., 2021), but data gathering, and quantification is still a barrier to this method used for resilience assessment. Simultaneously, considering the disadvantages of subjective judgement, the analytic hierarchy process (Tadić et al., 2014) is used to evaluate the resilience and identify its influential factors. As with other multiple elements system, process industry is a system consisting of many sub-systems, which determines the complexity of its structure and difficulty of conducting resilience assessment. Resilience assessment required us measuring it with system thinking (Pawar et al., 2021), i.e., investigating the system structure, understanding the dynamic behavior of system, and reducing its complexity. In recent years, with the development of computers science, a lot of mathematical models are applied for resilience assessment. However, human behaviors play a major role in the system of process plant and environmental protection, how to quantify these uncertainty and random factors properly for resilience assessment needs to be further considered.

Table 8
explicit information associated with cited author analysis.

Author	Frequency	Source	Author	centrality	Source
Hosseini S (2016)	84	(Hosseini et al., 2016)	Meerow S (2016)	0.11	(Meerow et al., 2016)
Panteli M (2017)	41	(Panteli et al., 2017)	Frazier TG (2013)	0.11	(Frazier et al., 2013)
Cutter SL (2016)	40	(Cutter, 2016)	Ayyub BM (2014)	0.09	(Ayyub, 2014)
Meerow S (2016)	35	(Meerow et al., 2016)	Asadzadeh A (2017)	0.09	(Asadzadeh et al., 2017)
Francis R (2014)	35	(Francis and Bekera, 2014)	Aldunce P (2015)	0.09	(Aldunce et al., 2015)

5. Contributions to process safety and environmental protection

In the above section, records are selected to review the resilience management based on the topic and timespan, and some literatures are not relevant with process safety or environmental protection. Thus, we changed our search strategies as: Topic = "Resilience engineering" OR "resilience assessment" OR "resilience quantification" OR "resilience management" OR "quantitative resilience assessment" OR "resilience network", the timespan was set as from 31 to 08–2012 to 31–08–2022, meanwhile, we select the ten most relevant journals with process safety and environmental protection as the sources, including "RELIABILITY ENGINEERING & SYSTEM SAFETY", "SAFETY SCIENCE", "INTERNATIONAL JOURNAL OF DISASTER RISK REDUCTION", "SUSTAINABILITY", "ECOLOGY AND SOCIETY", "WATER", "COGNITION TECHNOLOGY & WORK", "APPLIED ERGONOMICS", "ECOLOGICAL INDICATORS" and "SCIENCE OF THE TOTAL ENVIRONMENT", to carry out resilience analysis. Finally, a total of 344 records are highlighted.

The statistics characteristics of publications of countries and institutes are displayed in Fig. 14. The USA and China have seen the largest publications with frequency 134 and 119, respectively, followed by the

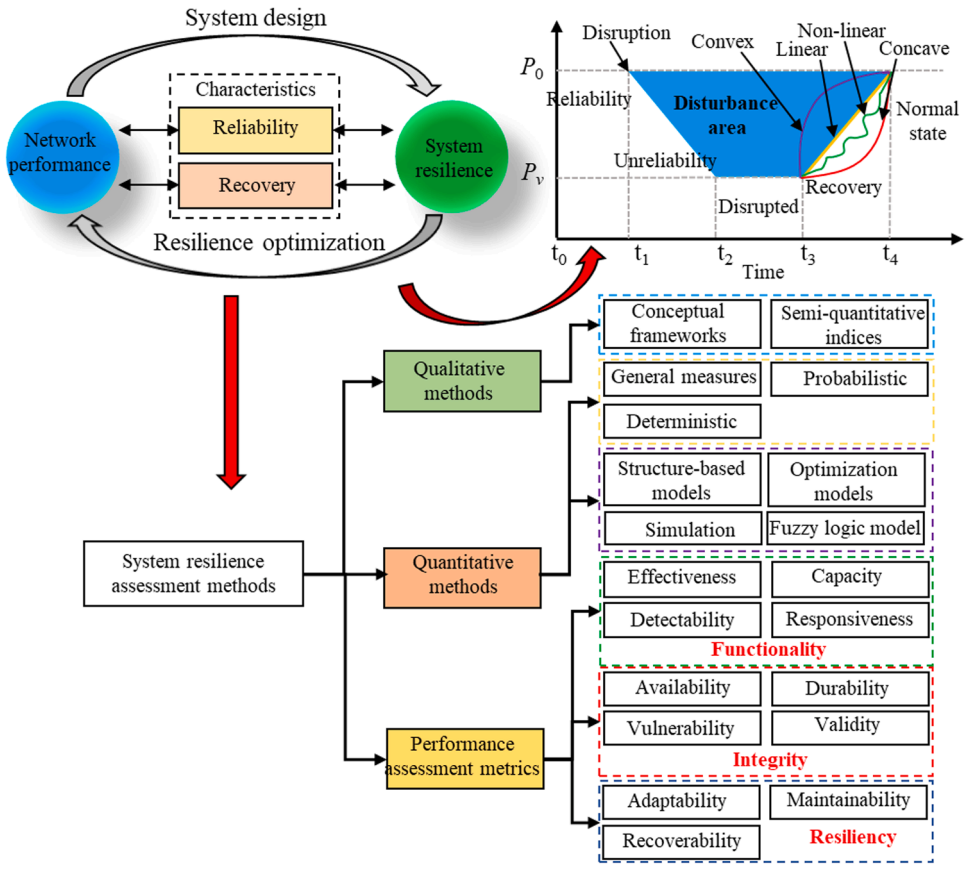
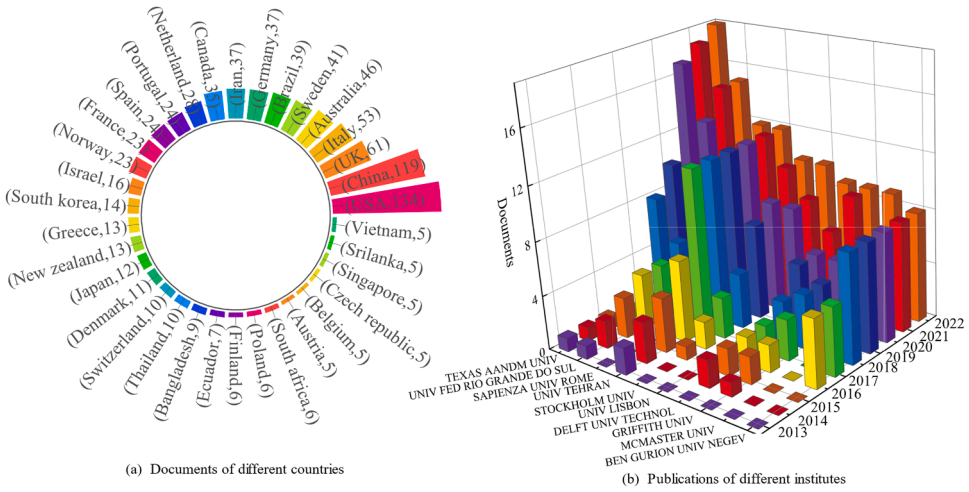


Fig. 13. resilience assessment methods summary.



(a) Documents of different countries

(b) Publications of different institutes

Fig. 14. Publication count of most relevant institutes and countries.

UK (61), Italy (53), Australia (46) and Sweden (41), while the frequency of remaining countries listed in Fig. 14(a) are less than 40. It is clear that the role of the USA and China is considerably important, making great contribution to the resilience research. Fig. 14(b) records the annual publications of main institutes, obviously, the institution "TEXAS AANDM UNIV" saw the shape increase from 1 to 19 during a period from 2013 to 2022. A similar trend was seen in the rest of countries from 0 to near 10. From the distribution characteristics of countries and institutions, a large proportion of publications are contributed by world powers, such as the USA and China. On the one hand, there is great demand for these countries to further explore more efficient solutions for resilience issues; on the other hand, the countries have enough energies and fundings to guarantee the scientific community carry out resilience research in these fields.

The analysis of authors, countries, and institutions, identifying the key literatures play a significant role in resilience research. Some of them are review articles regarding resilience definition, assessment, and its future development. One of the most important factors contributing to this phenomenon is that review articles are usually completed with multi-disciplines background based on literature statistics and full investigation, and it can provide valuable information for process safety and environmental protection. It can be found that the studies in nuclear

power and oil & gas production, are coinciding with process safety, and many methods and approaches for process safety are also accepted in resilience management. On the other hand, resilience management is not same developed for environmental protection. Some studies can be found, but when renewable energy, for example, wind power and hydrogen, is regarded as an approach of environmental protection, resilience management will play more roles in consideration of the instability in power generation and uncertainty in these novel techniques. Resilience in the network of renewable energy storage and transportation also deserves more attention in the future. It can be found in the bibliometric analysis that, the cluster around Azadeh, A, are mainly consisted by researchers whose research interests are within process safety.

More detailed evidence can be found from the density diagram of Fig. 15, where we extract the keywords of resilience management related to process safety, sustainability, and environmental protection. In this process, we exclude many keywords for general methodologies, for example, ‘‘simulation’’, and ‘‘modeling’’, as well as those for other applications, such as ‘‘railway’’ and ‘‘construction’’. As a result, only some words are included while we need to admit that they cannot reflect all studies for resilience management.

In Fig. 15, the color closer to red means more publications with the associated keyword. It is noticeable that safety and safety II are the most frequent keywords, and some words of applications such as refinery, nuclear industry and disaster resilience are around them. We can regard this cluster for general approaches in process safety. It is natural and fitting with the expectation that resilience engineering is closely related to the approaches for ensuring safety. On the other side, process/system safety and risk consist of a larger cluster with a lower density. In the neighborhood of process safety, the keywords of failure propagation and loss prevention are visualized, and they connect some theories and approaches, such as normal accident theory, ergonomics and emergency management.

6. Discussions and conclusions

6.1. Particular contributions

This review is conducted to explore the statistics characteristics of the studies on resilience management based on multiple tools, e.g., Citespace, Vosviewer and Bibliometric analysis. Each tool has its own advantage and disadvantage, utilizing three analysis tools can mine more valuable information from the data and improve the data visualization. In this study, “resilience” can be considered as a broad concept referring to a large volume of domains, thus, the assessment and management of resilience system are comprehensively counted referring to holistic, author and publication type analysis. Resilience assessment, as one of the core concepts in resilience management, is particularly reviewed through keywords cluster and cited author analysis. Finally, analysis regarding authors, institutions and countries is conducted through extracting data from the most relevant journals in process safety and environmental protection, aiming at highlighting the development in these domains. Compared to earlier reviews, this paper has not put energy on discussing the definition and resilience factors. Instead, the statistic characteristics of resilience research are understood using data mining methods, exploring the research hotspots based on the information that we mined, making it possible to analyze the development statues regarding resilience system objectively and comprehensively, especially in the field of process safety and environmental protection.

6.2. Findings and potential value for resilience management

In this study, the number of publications with respect to resilience engineering counted from 1997 and increased since 2012, which shows that this is a very active and increasingly productive research community. Among all the highly productive and relevant journals, Reliability engineering and system safety, and *Safety Science* are considered as the main sources contributing to the resilience engineering research. As a whole, “resilience engineering”, “management” and “climate change”

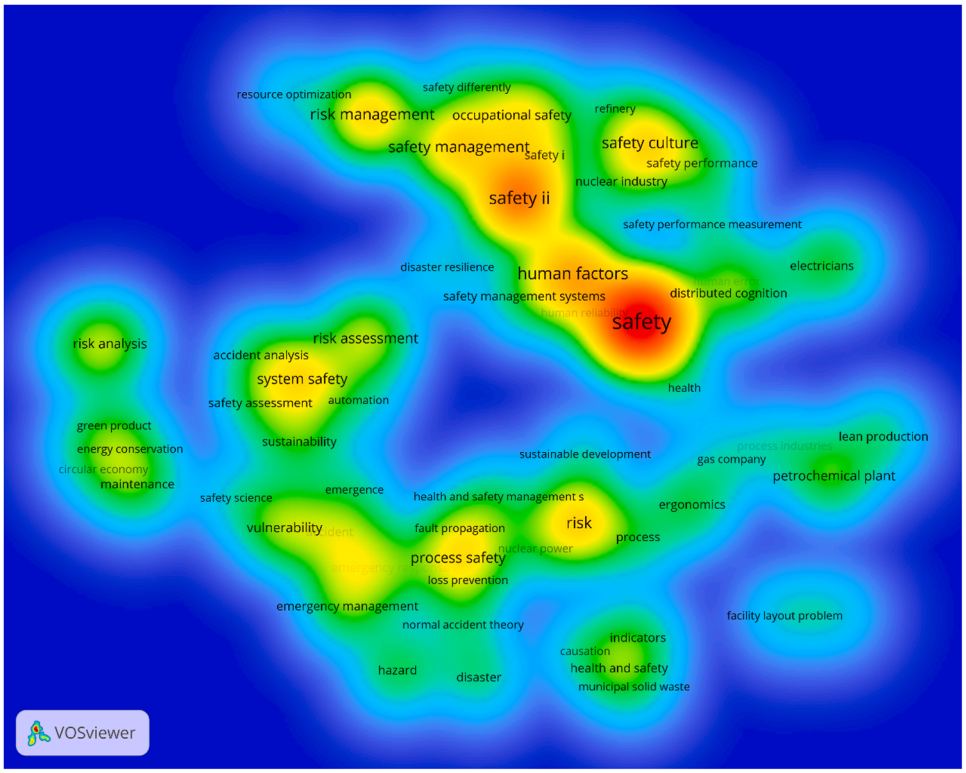


Fig. 15. Density of keywords related to process safety and environmental protection.

are the most frequent topic in the field of resilience. As for resilience management, “safety and human work related”, “health care related” and “process safety and hazard” are the main popular issues gaining more attention from the scientific community. This suggests that scholars’ emphasis is placed on the practical application of resilience management in industry and the cross-application of safety science. By comparison, resilience assessment focuses more on “extreme weather”, “urban resilience” and “family resilience” through keywords cluster analysis.

Co-citations of authors with multiple experience levels are common in resilience engineering due to its interdisciplinary background. Nonetheless, co-author analysis, citation analysis and co-citation analysis are the most effective tools for identifying the most beneficial and influential contributions. Among these countries/regions listed, the most strongly developed collaboration is between Iran and France, while the institutions Univ Tehran and Esfarayen Univ Technol have the closest collaboration. In terms of countries, the United States of America ranks first in the total citations list, while Canada has the highest average citations. In terms of institutions, Univ Tehran ranks first, while Georgia Inst Technol ranks highest when considering the average citations per article. Resilience assessment plays an important role in resilience management, to whom the main methods include investigate the affecting factors and analyze the performance loss before and after disruption events. In this study, the countries, institutions, influential authors, and publications are visualized, and commonly used metrics are summarized for quantitative assessment, which enables to explore more robust metrics for resilience measurement. With respect to the analysis conducted in the specific journals, it makes us focus on the research in our field, especially in process safety.

6.3. Limitations of this study

However, this review is conducted with some limitations. At first, the search strategies we applied for resilience analysis in this study include resilience assessment and resilience management. However, other important terms, e.g., resilience evaluation, haven’t been considered, resulting in the resilience research aren’t covered comprehensively. Secondly, the timeline of resilience assessment methods when it was first proposed, and its development and improvement haven’t been investigated combining with the visualization analysis. Finally, language bias reduces the systematic of this review, because the sources are analyzed based on the dataset obtained from WOS, that is, the language was limited to English and other documents published in other languages haven’t been considered. Nevertheless, the systematic review is the first attempt to systematically analyze the resilience management and its assessment methods, which provides valuable information for future studies.

6.4. Research perspectives

Resilience assessment and management are playing a major role in many fields. In the context of most previous reviews are focusing on the definition and metrics of resilience, this study analyzed the application, collaboration, and annual publications of resilience management, as well as further explored its development level in the specific journals regarding process safety and environment protection based on literature statistics analysis. The influential authors, affiliations and documents are highlighted, making it possible to focus on our research easily. In the field of process safety and environment protection, each research and resilience metrics has its own advantages and disadvantages, it is, therefore, difficult to highlight their performance with different background. The future investigation may put more energy on the collaboration of different countries and institutions, while international conferences should also be organized to strengthen the diversity and innovation in this field.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Aldunce, P., Beilin, R., Howden, M., Handmer, J., 2015. Resilience for disaster risk management in a changing climate: practitioners’ frames and practices. Glob. Environ. Change 30, 1–11.
Arassi, M., et al., 2015. Quantitative Assessment of Resilience in the operatives unitsof National Iranian Drilling Company (regional study: Khuzestan). J. Health Saf. Work 4 (4), p. 21-+.
Aria, M., Cuccurullo, C., 2017. bibliometrix: an R-tool for comprehensive science mapping analysis. J. Informetr. 11 (4), 959–975.
Asadzadeh, A., Kötter, T., Salehi, P., Birkmann, J., 2017. Operationalizing a concept: the systematic review of composite indicator building for measuring community disaster resilience. Int. J. Disaster risk Reduct. 25, 147–162.
Ayyub, B.M., 2014. Systems resilience for multihazard environments: definition, metrics, and valuation for decision making. Risk Anal. 34 (2), 340–355.
Azadeh, A., et al., 2014a. Performance evaluation of integrated resilience engineering factors by data envelopment analysis: the case of a petrochemical plant. Process Saf. Environ. Prot. 92 (3), 231–241.
Azadeh, A., et al., 2014b. Assessment of resilience engineering factors in high-risk environments by fuzzy cognitive maps: a petrochemical plant. Saf. Sci. 68, 99–107.
Azadeh, A., et al., 2016b. An integrated fuzzy simulation-mathematical programming approach for layout optimization by considering resilience engineering factors: a gas transmission unit. World J. Eng. 13 (6), 547–559.
Azadeh, A., et al., 2016c. A unique adaptive neuro fuzzy inference system for optimum decision making process in a natural gas transmission unit. J. Nat. Gas. Sci. Eng. 34, 472–485.
Azadeh, A., Haghighi, S.M., Salehi, V., 2015. Identification of managerial shaping factors in a petrochemical plant by resilience engineering and data envelopment analysis. J. Loss Prev. Process Ind. 36, 158–166.
Azadeh, A., Kolaee, M.H., Salehi, V., 2016a. The impact of redundancy on resilience engineering in a petrochemical plant by data envelopment analysis. Proc. Inst. Mech. Eng. Part O-J. Risk Reliab. 230 (3), 285–296.
Azadeh, A., Salehi, V., Mirzayi, M., 2016a. The impact of redundancy and teamwork on resilience engineering factors by fuzzy mathematical programming and analysis of variance in a large petrochemical plant. Saf. Health Work 7 (4), 307–316.
Bergstrom, J., van Winsen, R., Henriqson, E., 2015. On the rationale of resilience in the domain of safety: a literature review. Reliab. Eng. Syst. Saf. 141, 131–141.
Bergström, J., Van Winsen, R., Henriqson, E., 2015. On the rationale of resilience in the domain of safety: a literature review. Reliab. Eng. Syst. Saf. 141, 131–141.
de Carvalho, P.V.R., 2011. The use of Functional Resonance Analysis Method (FRAM) in a mid-air collision to understand some characteristics of the air traffic management system resilience. Reliab. Eng. Syst. Saf. 96 (11), 1482–1498.
de Carvalho, P.V.R., de Souza, A.P., Gomes, J.O., 2012. A computerized system to monitor resilience indicators in organizations. Work-a J. Prev. Assess. Rehabil. 41, 2803–2809.
Castillo-Borja, F., Vázquez-Román, R., Quiroz-Pérez, E., et al., 2017. A resilience index for process safety analysis. J. Loss Prev. Process Ind. 50, 184–189.
Chen, C., 2004. Searching for intellectual turning points: progressive knowledge domain visualization. Proc. Natl. Acad. Sci. 101 (suppl_1), 5303–5310.
Chen, C., 2006. CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature. J. Am. Soc. Inf. Sci. Technol. 57 (3), 359–377.
Clay-Williams, R., Hounsgaard, J., Hollnagel, E., 2015. Where the rubber meets the road: using FRAM to align work-as-imagined with work-as-done when implementing clinical guidelines. Implement. Sci. 10.
Costella, M.F., Saurin, T.A., Guimares, L.B.D., 2009. A method for assessing health and safety management systems from the resilience engineering perspective. Saf. Sci. 47 (8), 1056–1067.
Costella, M.F., Saurin, T.A., Guimarães, L.B.d.M., 2009. A method for assessing health and safety management systems from the resilience engineering perspective. Saf. Sci. 47 (8), 1056–1067.
Cutter, S.L., 2016. The landscape of disaster resilience indicators in the USA. Nat. Hazards 80 (2), 741–758.
Dinh, L.T.T., et al., 2012. Resilience engineering of industrial processes: Principles and contributing factors. J. Loss Prev. Process Ind. 25 (2), 233–241.
Dolif, G., et al., 2013. Resilience and brittleness in the ALERTA RIO system: a field study about the decision-making of forecasters. Nat. Hazards 65 (3), 1831–1847.

Eck, N.Jv , Waltman, L., Manual for VOSviewer version 1.6.15. 2020.
Elango, B., Rajendran, P., 2012. Authorship trends and collaboration pattern in the marine sciences literature: a scientometric study. Int. J. Inf. Dissem. Technol. 2 (3), 166–169.
Ellis, L.A., et al., 2019. Patterns of resilience: a scoping review and bibliometric analysis of resilient health care. Saf. Sci. 118, 241–257.
Erik, H., 2012. FRAM: the Functional Resonance Analysis Method: Modelling Complex Socio-technical Systems, First ed. CRC Press, London, p. 160.
Falegnami, A., et al., 2022. Unveil key functions in socio-technical systems: mapping FRAM into a multilayer network. Cogn. Technol. Work 23.
Francis, R., Bekera, B., 2014. A metric and frameworks for resilience analysis of engineered and infrastructure systems. Reliab. Eng. Syst. Saf. 121, 90–103.
Frazier, T.G., Thompson, C.M., Dezzani, R.J., Butsick, D., 2013. Spatial and temporal quantification of resilience at the community scale. Appl. Geogr. 42, 95–107.
Gasser, Patrick, et al., 2021. A review on resilience assessment of energy systems. Sustain. Resilient Infrastruct. 273–299, 6.5.
Gattola, V., et al., 2018. Functional resonance in industrial operations: a case study in a manufacturing plant. Ifac Pap. 51 (11), 927–932.
Gomes, J.O., et al., 2009. Resilience and brittleness in the offshore helicopter transportation system: the identification of constraints and sacrifice decisions in pilots' work. Reliab. Eng. Syst. Saf. 94 (2), 311–319.
Haimes, Y.Y., 2009. On the complex definition of risk: a systems-based approach. Risk Anal.: Int. J. 29 (12), 1647–1654.
Hickford, A.J., et al., 2018. Resilience engineering: theory and practice in interdependent infrastructure systems. Environ. Syst. Decis. 38 (3), 278–291.
Holling, C.S., 1973a. Resilience and stability of ecological systems. Annu, Rev. Ecol. Syst. 1–23.
Holling, C.S., 1973b. Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 4 (1), 1–23.
Hollnagel, E., 2004. Barriers and Accident Prevention, First ed. Routledge, London, p. 242.
Hollnagel, E., 2009. The ETTO Principle: Efficiency-Thoroughness Trade-Off, First ed. CRC Press, London, p. 162.
Hollnagel, E., et al., 2011. Resilience Engineering in Practice: A Guidebook, First ed. CRC Press, London, p. 362.
Hollnagel, E., 2014a. Resilience engineering and the built environment. Build. Res. Inf. 42 (2), 221–228.
Hollnagel, E., 2014b. Safety–I and Safety–II The Past and Future of Safety Management, First ed. CRC Press, London, p. 200.
Hollnagel, E., Woods, D.D., 2005. Joint Cognitive Systems-Foundations of Cognitive Systems Engineering, First ed. CRC Press, Boca Raton, p. 240.
Hollnagel, E., Nemeth, C.P., 2009. Resilience Engineering. In: Perspectives, Volume 2. CRC Press, London, p. 310.
Hollnagel, E., Fujita, Y., 2013. The Fukushima disaster - systemic failures as the lack of resilience. Nucl. Eng. Technol. 45 (1), 13–20.
Hollnagel, E., Woods, D.D., Leveson, N., 2006. Resilience Engineering: Concepts and Precepts, First ed. CRC Press, London, p. 416.
Hosseini, S., Barker, K., Ramirez-Marquez, J.E., 2016. A review of definitions and measures of system resilience. Reliab. Eng. Syst. Saf. 145, 47–61.
Huber, G.J., Gomes, J.O., de Carvalho, P.V.R., 2012. A program to support the construction and evaluation of resilience indicators. Work-a J. Prev. Assess. Rehabil. 41, 2810–2816.
Huber, S., et al., 2009. Learning from organizational incidents: resilience engineering for high-risk process environments. Process Saf. Prog. 28 (1), 90–95.
Jafari, M.J., et al., 2018. Indicators of organizational resilience in critical sociotechnical systems: a qualitative study for the refinery complex. Health Scope 7 (3), 5.
JensRasmussen, 1997. Risk management in a dynamic society: a modelling problem. Saf. Sci. 27 (2–3), 183–213.
Leveson, N., 2004. A new accident model for engineering safer systems. Saf. Sci. 42 (4), 237–270.
Li, J., Goerlandt, F., Reniers, G., 2021. An overview of scientometric mapping for the safety science community: Methods, tools, and framework. Saf. Sci. 134.
Meerow, S., Newell, J.P., Stults, M., 2016. Defining urban resilience: a review. Landsc. Urban Plan. 147, 38–49.
Mishra, D.K., et al., 2021. A review on resilience studies in active distribution systems. Renew. Sustain. Energy Rev. 135, 110201.
Nemeth, C.P., Hollnagel, E., 2008. Resilience Engineering. In: Perspectives, Volume 1. CRC Press, London, p. 352.
Nodoushan, R.J., et al., 2017. Identifying and ranking of organizational resilience indicators of refinery complex using fuzzy TOPSIS. J. Health Saf. Work 7 (3), 219–232.
Panteli, M., Mancarella, P., Trakas, D.N., Kyriakides, E., Hatziargyriou, N.D., 2017. Metrics and quantification of operational and infrastructure resilience in power systems. IEEE Trans. Power Syst. 32 (6), 4732–4742.
Patriarca, R., et al., 2017. myFRAM: An Open Tool Support for the Functional Resonance Analysis Method. 2017a 2nd International Conference on System Reliability and Safety. 2017. 439–443.
Patriarca, R., et al., 2018. Resilience engineering: current status of the research and future challenges. Saf. Sci. 102, 79–100.
Patriarca, R., Bergstrom, J., 2017. Modelling complexity in everyday operations: functional resonance in maritime mooring at quay. Cogn. Technol. Work 19 (4), 711–729.
Patriarca, R., Di Gravio, G., Costantino, F., 2017a. A Monte Carlo evolution of the Functional Resonance Analysis Method (FRAM) to assess performance variability in complex systems. Saf. Sci. 91, 49–60.
Patriarca, R., Bergström, J., Gravio, G.D., 2017b. Defining the functional resonance analysis space: Combining Abstraction Hierarchy and FRAM. Reliab. Eng. Syst. Saf. 165, 34–46.
Pawar, B., et al., 2021. Applications of resilience engineering principles in different fields with a focus on industrial systems: a literature review. J. Loss Prev. Process Ind. 69, 104366.
Perrow, C., 1984. Normal Accidents: Living with High-Risk Technologies. Basic Books, New York.
Raben, D.C., et al., 2017. Proposing leading indicators for blood sampling: application of a method based on the principles of resilient healthcare. Cogn. Technol. Work 19 (4), 809–817.
Raben, D.C., et al., 2018. Application of a non-linear model to understand healthcare processes: using the functional resonance analysis method on a case study of the early detection of sepsis. Reliab. Eng. Syst. Saf. 177, 1–11.
Righi, A.W., Saurin, T.A., Wachs, P., 2015. A systematic literature review of resilience engineering: Research areas and a research agenda proposal. Reliab. Eng. Syst. Saf. 141, 142–152.
Rosso, C.B., Saurin, T.A., 2018. The joint use of resilience engineering and lean production for work system design: a study in healthcare. Appl. Ergon. 71, 45–56.
Saurin, T.A., et al., 2014. The design of scenario-based training from the resilience engineering perspective: a study with grid electricians. Accid. Anal. Prev. 68, 30–41.
Saurin, T.A., Carim, G.C., 2011. Evaluation and improvement of a method for assessing HSMS from the resilience engineering perspective: a case study of an electricity distributor. Saf. Sci. 49 (2), 355–368.
Saurin, T.A., Wachs, P., Henriqson, E., 2013. Identification of non-technical skills from the resilience engineering perspective: a case study of an electricity distributor. Saf. Sci. 51 (1), 37–48.
Shirali, G., et al., 2012a. Assessing resilience engineering based on safety culture and managerial factors. Process Saf. Prog. 31 (1), 17–18.
Shirali, G., Shekari, M., Angali, K.A., 2018. Assessing reliability and validity of an instrument for measuring resilience safety culture in sociotechnical systems. Saf. Health Work 9 (3), 296–307.
Shirali, G.A., et al., 2016b. Assessment of resilience engineering factors based on system properties in a process industry. Cogn. Technol. Work 18 (1), 19–31.
Shirali, G.A., Mohammadfam, I., Ebrahimipour, V., 2013. A new method for quantitative assessment of resilience engineering by PCA and NT approach: a case study in a process industry. Reliab. Eng. Syst. Saf. 119, 88–94.
Shirali, G.A., Azadian, S., Saki, A., 2016a. A new framework for assessing hospital crisis management based on resilience engineering approach. Work 54 (2), 435–444.
Shirali, G.A., Azadian, S., Saki, A., 2016a. A new framework for assessing hospital crisis management based on resilience engineering approach. Work-a J. Prev. Assess. Rehabil. 54 (2), 435–444.
Shirali, G.A., Shekari, M., Angali, K.A., 2016b. Quantitative assessment of resilience safety culture using principal components analysis and numerical taxonomy: a case study in a petrochemical plant. J. Loss Prev. Process Ind. 40, 277–284.
Shirali, G.H.A., et al., 2012b. Challenges in building resilience engineering (RE) and adaptive capacity: a field study in a chemical plant. Process Saf. Environ. Prot. 90 (2), 83–90.
Steen, R., Aven, T., 2011. A risk perspective suitable for resilience engineering. Saf. Sci. 49 (2), 292–297.
Tadić, D., Aleksić, A., Stefanović, M., Arsovski, S., 2014. Evaluation and ranking of organizational resilience factors by using a two-step fuzzy AHP and fuzzy TOPSIS. Math. Probl. Eng. 2014.
Wachs, P., et al., 2016. Resilience skills as emergent phenomena: a study of emergency departments in Brazil and the United States. Appl. Ergon. 56, 227–237.
Wachs, P., Righi, A.W., Saurin, T.A., 2012. Identification of non-technical skills from the resilience engineering perspective: a case study of an electricity distributor. Work-a J. Prev. Assess. Rehabil. 41, 3069–3076.
Woods, D.D., 2015. Four concepts for resilience and the implications for the future of resilience engineering. Reliab. Eng. Syst. Saf. 141, 5–9.
Xue, X.L., Wang, L., Yang, R.J., 2018. Exploring the science of resilience: critical review and bibliometric analysis. Nat. Hazards 90 (1), 477–510.
Yarveisy, R., Gao, C., Khan, F., 2020. A simple yet robust resilience assessment metrics. Reliab. Eng. Syst. Saf. 197, 106810.
Yodo, N., Wang, P., 2016. Engineering resilience quantification and system design implications: a literature survey. J. Mech. Des. 138 no. 11, 111408.