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Exploring the Implementation of Safety Resilience Assessment in Industries: A Systematic Literature Review

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Abstract

Safety Resilience discusses how a work process can run properly not only aims at preventing adverse events, but also increasing work productivity and effectiveness by increasing resilience. The concept of resilience has been widely suggested as safety management due to its ability to support organizations to continue operating even when facing unexpected demands or scale disruptions by improving their day-to-day performance. This study used a systematic literature review to explore the implementation of safety resilience in various industries. The results showed that 50% of articles used the Resilience Assessment Grid instrument to measure safety resilience in the workplace. In brief, increased safety resilience positively improves work performance and organizational safety.

Keywords: assessment, resilience, resilience engineering, resilience assessment grid, safety resilience

Introduction

Along with time, safety science has developed from Safety I to Safety II. In Safety I, an accident or near miss is regarded as an incident that occurs due to workers not completing work according to applicable procedures; hence, the focus of Safety I is to develop preventive measures through rules made for controlling humans to work without human error.[1,2] The basis of this perspective, particularly in terms of patient safety, for a safety improvement, is less precise, and several experts argued that such efforts might inadvertently create more confounding, which could ultimately hinder the safety improvement.[3–5] In Safety II, safety management focuses on assisting people to deal with complex conditions that arise while under pressure. This concept was introduced to clarify the distinction between two perspectives on safety (Safety I and Safety II) and their underlying assumptions.[2] Safety II discusses how a work process could run properly to prevent adverse events and boost productivity and effectiveness by uplifting resilience.[6,7] The paradigm shift from Safety-I to Safety-II would also help improve safety practices in a company.[8]

The resilience concept was introduced by Hollnagel, Woods, and Levenson in their book entitled Resilience Engineering: Concept and Receipt in 2006. The resilience concept has been widely suggested as safety management because it supports organizations in continuing to operate even when facing demands or scaling unexpected disruptions by improving their daily performance.[9,10] This improvement in performance includes four potential aspects: the ability to respond to changes and disturbances, monitor conditions that may affect organizational performance, learn the rights and wrongs of a condition, and take anticipatory action.[6] The resilience term is widely applied across multiple disciplines. However, the development of quantitative metrics for sociotechnical systems and establishing standards and processes are still in their infancy.[11,12] To ensure an effective implementation of resilience engineering, a rigorous methodology is essential. This necessitates a transdisciplinary approach to resilience engineering, drawing on expertise from diverse sectors, including industrial sectors, to enhance resilience.[12,13]

For the industrial sectors, especially those with a high risk of accidents, good safety management is the key to production sustainability. In addition, much complexity in terms of technology and business development exists in the 4.0

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industrial era. Companies are required to develop following such complexity in order to continue to run productively. Applying the safety resilience concept could help companies demonstrate their flexibility in adapting to various changes that occur; thus, outcomes or products produced remain in line with the company's goals.[14] Several industries which have implemented the resilience concept are aviation, health services, chemical and petrochemical industries, nuclear power plants, and railroads.[15] Therefore, this study aimed to explore safety resilience measurement methods in various industries.

Method

A systematic literature review (SLR) was applied to explore safety resilience measurement methods in various industries. The SLR aims to identify, evaluate, and assess the results of prior studies which are relevant to a particular research question or topic.[16] The SLR must use methodological and transparent steps, one of which is the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) method, which is comprehensive for conducting SLRs in various research fields. Therefore, this study applied the PRISMA method, which comprises of four stages: identification, screening, eligibility, and data abstraction and analysis.[17,18]

Identification is the stage of identifying research objectives and objects. This study aimed to discuss safety resilience measures in various industries through SLRs. The unit of analysis for this study was scientific journal articles with keywords "Safety Resilience" OR "Safety Resilience Assessment" OR "Resilience Assessment Grid" via Scopus, ScienceDirect, and SpringerLink. A total of 433 articles was found through search results, consisting of 87 Scopus articles, 167 ScienceDirect articles, and 179 SpringerLink articles. In the next stage, 433 articles were screened according to the inclusion and exclusion criteria determined for this study. The inclusion criteria were research articles and case studies in English from the integrated journals Q1-Q3 within a period of 2010-2022. While, the exclusion criteria were literature review, conference proceedings, and non-English books existing prior to 2010 with Q4 criteria.

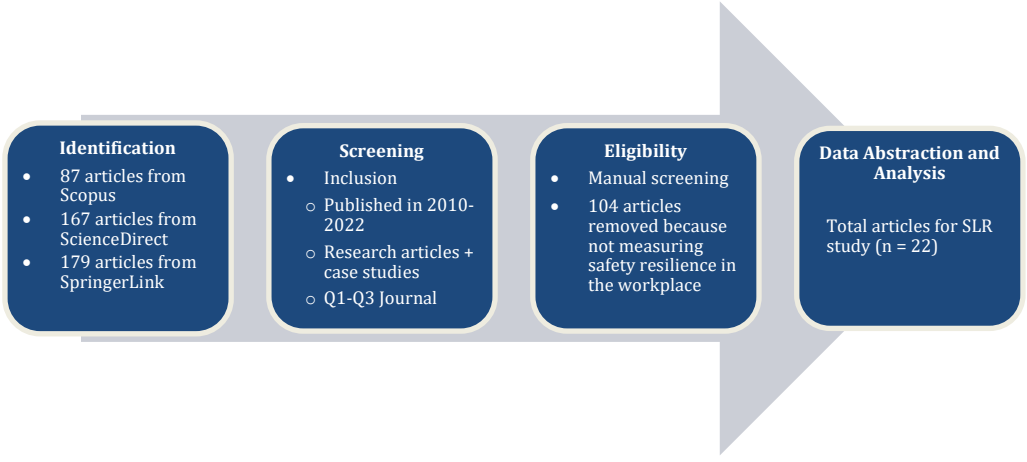

Figure 1. Article Selection Process Based on the PRISMA Method

The screening results revealed 126 articles met the inclusion criteria and they went to the following eligibility stage, manually filtering articles to obtain some which were feasible and truly suited to the research objectives. The screening was carried out using specified criterion: the article discussed the results of research on measuring resilience in the work environment. A total of 104 articles were excluded at this stage because they did not measure safety resilience in the workplace. The last stage was data abstraction and analysis. The remaining 22 articles were evaluated, reviewed, and analyzed by identifying similarities and differences in indicators, measurement methods, and results discussed in the articles.

Results

A total of 22 articles were reviewed (Table 2). Five articles came from the healthcare industry, three articles from the construction industry, three articles from the petrochemical industry, two articles from electricity industry, two articles from nuclear industry, one article from oil and gas industry, one article from aviation, one article from the process industry, one article from maritime sector, one article from road transportation sector, one article from chemical industry, and one article from solid waste company sector. Most articles came from scientific journals with impact quartiles of Q1 (68%) and Q2 (32%), more than half came from journals of Safety Science (41%), Safety (9%), Journal of Loss Prevention in the Process Industries (9%), Progress in Nuclear Energy (5%), Mathematical Problems in Engineering (5%), Journal of Building Engineering (5%), Applied Ergonomic (5%), Annals of Nuclear Energy (5%), PLoS One (4%), Safety and Health at Work (4%), Reliability Engineering and System Safety (4%), and Journal of Evaluation in Clinical Practice (4%).

Table 1. Characteristics of Articles by Year, Industry, Journal Name, and Journal Impact Quartile

Year	Industry	Title of Journal	Journal Impact Quartile	Number of Articles
2022	Health Care	Safety Science	Q1	1
2022	Health Care	PLoS One	Q1	1
2022	Electricity	Mathematical Problems in Engineering	Q2	1
2021	Construction	Safety Science	Q1	1
2021	Maritime	Safety	Q2	1
2021	Health Care	Safety Science	Q1	1
2021	Nuclear	Progress in Nuclear Energy	Q2	1
2021	Construction	Journal of Building Engineering	Q1	1
2020	Health Care	Safety Science	Q1	1
2020	Construction	Applied Ergonomics	Q1	1
2020	Road Transportation	Safety	Q2	1
2020	Chemical	Safety Science	Q1	1
2021	Aviation	Safety Science	Q1	1
2018	Health Care	Journal of Evaluation in Clinical Practice	Q2	1
2018	Solid Waste	Safety Science	Q1	1
2018	Nuclear	Annals of Nuclear Energy	Q1	1
2018	Petrochemical	Safety and Health at Work	Q1	1
2017	Oil and Gas	Journal of Loss Prevention in the Process Industries	Q2	1
2016	Petrochemical	Journal of Loss Prevention in the Process Industries	Q2	1
2016	Petrochemical	Safety Science	Q1	1
2013	Process Industry	Reliability Engineering and System Safety	Q1	1
2011	Electricity	Safety Science	Q1	1
			TOTAL	**22**

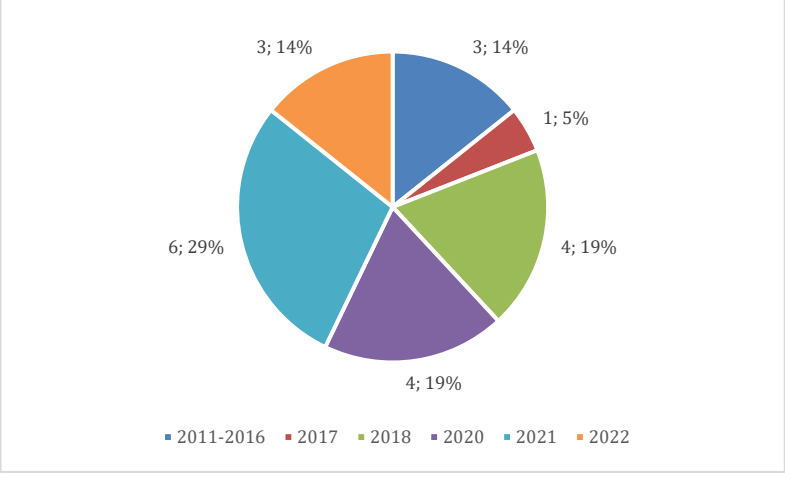

Figure 2. Article Distribution by Year

Figure 2 shows the year distribution of articles taken from 2011 to 2022. A total of 29% of articles come from 2021, 19% of articles come from 2018 and 2020, followed by 14% of articles from 2022 and under 2016. Only 5% of the articles come from 2017. Figure 3 shows a distribution of 12 industries based on the review results of the identified articles.

Healthcare is the largest industry at 23%, followed by construction industry at 14% and nuclear and electricity at 9%.

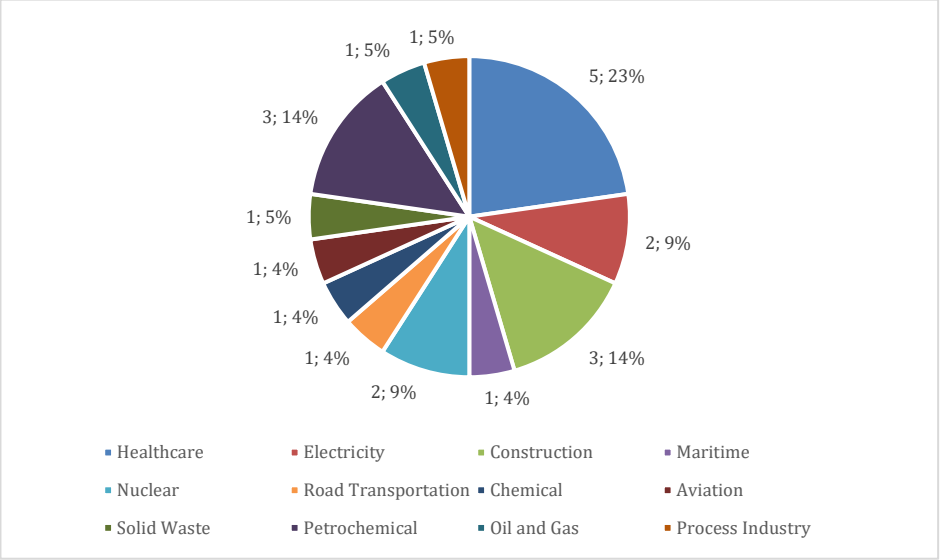

Figure 3. Article Distribution by Industry

Table 2. Detailed Review of Articles

No.	Article Title / Journal / DOI	Industry	Authors	Objective & Participant	Method Used to Measure Safety Resilience	Resilience Result
1.	The resilient potential behaviours in an Internal Medicine Department: Application of Resilience Assessment Grid[19] PLoS One, 2022: 17 (20) https://doi.org/10.1371/journal.pone.0276178	Health Care	Safi *et al.*	**Objective** Understanding and assessing the resilience performance of the Internal Medicine Department at Denmark's General Hospital using RAG **Participants** ● Doctors, middle managers, and nurses. (n = 44 in Survey 1 and n=36 in Survey 2) ● Purposive and snowball sampling	● Quantitative research ● Instrument: RAG Questionnaire ● Scoring: a 5-point Likert scale (1–5) (e.g., never, rarely, sometimes, often, or always ● The survey was conducted in two stages (January 2021 and February 2022) to see changes in resilience performance ● Descriptive analysis	● From January 2021 to February 2022, all resilience abilities (respond, monitor, learn, and anticipate) have decreased ● Respond decreased from 2.82 to 2.66 ● Monitor decreased from 3.09 to 2.96 ● Learn decreased from 2.94 to 2.75 ● Anticipate decreased from 2.83 to 2.69
2.	Measurement of resilience potentials in Emergency Departments: Applications of a tailored Resilience Assessment Grid[20] Saf Sci, 2020: 121 https://doi.org/10.1016/j.ssci.2019.09.012	Health Care	Chuang *et al.*	**Objective** Assessing the resilience performance of Emergency Department in public and private hospitals through 4 resilience abilities **Participants** 1 Emergency Department's director, administrative staff, doctor, and head nurse from 4 hospitals (n = 16)	● Qualitative research ● Interview using RAG guidelines and some Emergency Department-tailored questions. ● Answers are coded as 1 to 4 ● Descriptive analysis	● Public hospitals (Hospital C + D) have a higher group score of all resilience abilities than private hospitals (Hospital A + B). ● Respond: The highest (61.50% by Hospital C), the lowest (33.28% by Hospital A). ● Monitor: The highest (36.61% by Hospital C), the lowest (16.96% by Hospital B). ● Learn: The highest (86.46% by Hospital C), the lowest (64.24% by Hospital A). ● Anticipate: The highest (58.33% by Hospital C), the lowest (17.71% by Hospital A).
3.	Monitoring complexity and resilience in construction projects: The	Construction	Peñaloza *et al.*	**Objective** Identify opportunities to improve SPMS based on analysis of source complexity and	● Semi-quantitative research ● Measure resilience: Interview with RAG guideline	● Ability to respond: Project A (3.3), Project B (4.1), Project C (3.8). ● Ability to monitor: Project A (3.0), Project B (3.5), Project C (3.6).

No.	Article Title / Journal / DOI	Industry	Authors	Objective & Participant	Method Used to Measure Safety Resilience	Resilience Result
	contribution of safety performance measurement systems.[21] Appl Ergonom, 2022: 82 https://doi.org/10.1016/j.apergo.2019.102978			resilience in construction based on case studies in Brazil (Project A) and Chile (Project B & C). **Participants** Project manager, safety engineer, and safety technician (n = 4)	• Answers are coded as 0 (missing), 1 (deficient), 2 (unacceptable), 3 (acceptable), 4 (satisfactory), and 5 (excellent). • Documents analyzed: Standardized operating procedures, description of performance indicators, checklists, safety and production schedules, and safety reports. • Descriptive analysis	• Ability to learn: Project A (2.1), Project B (2.5), Project C (2.7). • Ability to anticipate: Project A (2.3), Project B (2.7), Project C (2.8). • Based on RAG and TOE implementation, there are 16 opportunities for improvements in the SPMS of the three companies.
4.	Measuring resilience potentials: A pilot program using the Resilience Assessment Grid[22] Saf, 2020: 6 (4) https://doi.org/10.3390/safety6040051	Road Transportation	Klockner *et al.*	**Objective** Measuring 4 potential resilience (respond, monitor, learn, and anticipate) in transport companies in Queensland **Participants** Middle management and supervisory positions at a single transport organization in Queensland (n = 15)	• Quantitative research • Instrument: RAG Questionnaire distributed by e-mail • Answers category: "Yes," "No," and "Unknown" • Not using scoring • The level of each potential resilience is analyzed based on the participant who answered "Yes" • Descriptive analysis	• Potential to learn: 83.3% • Potential to respond: 77% • Potential to anticipate: 52.9% • Potential to monitor: 41.3%
5.	A resilience engineering-based framework for assessing safety performance measurement systems: A study in the construction industry[23] Saf Sci, 2021: 142 https://doi.org/10.1016/j.ssci.2021.105364	Construction	Peñaloza *et al.*	**Objective** Assess 4 potential resilience and identify opportunities for improvement of SPMS **Participant** Project manager, site manager, safety coordinator, foreman, 6 front-line workers (n = 10)	• Semi-quantitative research • Instrument: RAG questionnaire • Scoring RAG: 6-point Likert scale 0 (missing), 1 (deficient), 2 (unacceptable), 3 (acceptable), 4 (satisfactory), 5 (excellent) • Documents analyzed: safety indicators, weekly safety reports, HSE non-conformity database, booklets, job safety analysis, standardized operating procedures, and the weekly work schedule. • Descriptive analysis	• Average score: Respond (2.9), Monitor (3.4), Learn (3.7), Anticipate (3.5). • There are 8 opportunities for improvements in the SPMS based on RAG, TOE, and RE implementation.
6.	A multicountry comparative survey about organizational resilience in anaesthesia[24] J Eval Clin Pract, 2018: 24 https://doi.org/10.1111/jep.13054	Health Care	Falegnami *et al.*	**Objective** Testing the AHP-RAG questionnaire to measure anesthesiologist resilience across countries. **Participants** Anesthesiologists from 16 nations (n = 172)	• Quantitative research • Instrument: RAG questionnaire with a 5-point scale, questionnaire distributed by e-mail • Scoring: using AHP framework (each question has a different value weight)	• The α level of Cronbach analysis is 0.910 → Has an adequate level of interitem reliability (>0.700). • FA and PCA confirmed the absence of underlying unexpected factors. • Implementing the AHP-RAG questionnaire is too complicated and time-consuming

No.	Article Title / Journal / DOI	Industry	Authors	Objective & Participant	Method Used to Measure Safety Resilience	Resilience Result
					• Construct validity using FA and PCA	
7.	Analysis of the Safety Resilience Implementation in the Maritime Industry at Public and Private Companies (A Case Study in Indonesia)[25] Saf, 2021: 7 (56) https://doi.org/10.3390/safety7030056	Maritime	Djunaidi *et al.*	**Objective** Analyzing the implementation of safety resilience in the Indonesian maritime sector **Participants** • Key informant: designated person ashore, Triangulation informant: quality health safety environment officer • Purposive sampling technique	• Semi-quantitative research • Collection of data from documents and interviews • Interview based on RAG + questions according to the research topic • Descriptive analysis	• The level of implementation of resilience in public companies is 75.1%, while in private companies, 70.2% • Resilience abilities in public and private companies: Respond (80%), Learn (74.62%), Monitor (70.77%), Anticipate (66.92%) • Based on the results of the resilience assessment, there are 4 recommendations proposed to the company
8.	How to identify key players that contribute to resilient performance: A social network analysis perspective[26] Saf Sci, 2022: 148 https://doi.org/10.1016/j.ssci.2021.105648	Health Care	Bertoni *et al.*	**Objective** Identify health workers who contribute the most (key players) to resilience performance using Social Network Analysis **Participants** Doctors, nurses, nurse technicians, allied health professionals (n = 133)	• Semi-quantitative research • Resilience is measured using RAG with 5 scales (1 = never, 2 = less than once a month, 3 = one to three times a month, 4 = one to three times a week, 5 = daily) • The 10 participants with the highest score (10 top players) will enter the follow-up interview stage • Data analysis: Network metric calculations and sociogram development using UCINET software • Descriptive analysis	• Doctors, nurses, and nurse technicians are the professions most frequently included in the top-10 players based on resilience scores • The highest score in resilience abilities: Monitor by a doctor (DR169, Score = 1204.7), Anticipate (N135, Score = 1217.5), Respond by a nurse (N135, Score = 1318.0), Learn by a nurse (N94, Score = 1371.9).
9.	Monitor, anticipate, respond, and learn: Developing and interpreting a multilayer social network of resilience abilities.[27] Saf Sci, 2021: 136 https://doi.org/10.1016/j.ssci.2020.105148	Health Care	Bertoni *et al.*	**Objective** Develop and interpret multilayer resilience networks **Participants** Doctors, nurses, nurse technicians, allied health professionals (n = 133)	• Semi-quantitative research • Resilience is measured using RAG with 5 scales (1 = never, 2 = less than once a month, 3 = one to three times a month, 4 = one to three times a week, 5 = daily). • Interviewed 2 doctors and 3 nurses that stood out based on actor-centered metrics at the layer level • Research phase: Data collection, multilayer modeling (WAI and WAD networks), and data analysis. • Multilayer network data analysis: (i) actor-centered	• Only actor N94 (a nurse) appears among the top-10, both in the multilayer and the single layer, for both WAI and WAD • All interlayer correlation values are in the interval [0.78; 0.79] → This shows that social interaction is strong in terms of contributing simultaneously to the four abilities. • All assortativity correlations are within the interval [0.98; 0.99] → This indicates there is a cluster formation of high-level and low-level actor groups that can hinder multiple perspectives when monitoring, anticipating, responding, and learning.

No.	Article Title / Journal / DOI	Industry	Authors	Objective & Participant	Method Used to Measure Safety Resilience	Resilience Result
					metrics (workers) (ii) layer-centered metrics (4 resilience abilities) ● Descriptive analysis	
10.	Identification of gaps in safety management systems from the resilience engineering perspective in upper and lower-tier enterprises[28] Saf Sci, 2020: 130 https://doi.org/10.1016/j.ssci.2020.104851	Chemical Industry	Pęciłło M.	**Objective** Assess which of the four resilience pillars predominate at the upper and lower-tier companies in Poland. **Participants** Workers in OSH departments and line managers responsible for safety performance from 14 upper companies and 16 lower companies	● Quantitative research ● Resilience is measured using RAG with 5 scales (5 = strongly agree, 4 = agree, 3 = neutral, = disagree, 1 = strongly disagree) ● Descriptive analysis	● The ability to respond has the highest score, and the ability to learn has the lowest score, especially regarding safety information. ● The use of leading indicators is more dominant than lagging indicators.
11.	Composite leading indicator to assess the resilience engineering in occupational health & safety in municipal solid waste management companies[29] Saf Sci, 2018: 108 https://doi.org/10.1016/j.ssci.2018.04.014	Solid Waste	Romero *et al.*	**Objective** Develop a quantitative evaluation method of CLI for Resilience in the Municipal Solid Waste Sector **Participants** Collection and delivery service workers from a solid urban waste company in the city of Málaga, Spain (n = 205)	● Quantitative research ● Resilience is measured using CLI (Shirali *et al.*, 2013), including top management commitment, just culture, culture of learning, awareness and opacity, preparedness, and flexibility ● The questionnaire has a 5-point Likert scale (1 = very low, 2 = low, 3 = medium, 4 = high, 5 = very high). ● Descriptive analysis	● Maintenance operator has the highest resilience score (3.59), driver has the lowest score (3.18) ● Driver has the lowest score in all indicators (top management commitment, just culture, culture of learning, awareness and opacity, preparedness, and flexibility).
12.	A new method for quantitative assessment of resilience engineering by PCA and NT approach: A case study in a process industry[30] Reliab Eng Syst Saf, 2013: 199 http://dx.doi.org/10.1016/j.ress.2013.05.003	Process Industry	Shirali *et al.*	**Objective** Conduct a quantitative assessment of Resilience Engineering using a questionnaire based on PCA **Participants** Managers, supervisors, and operators from 11 work units (n = 88)	● Quantitative Research ● Resilience is measured using CLI: Top management commitment, just culture, culture of learning, awareness and opacity, preparedness, and flexibility ● The questionnaire has a 5-point Likert scale from "strongly disagree" to "strongly agree" ● Descriptive analysis using PCA	● Storage tanks unit has a highest PCA final score (74.34). Technical inspection unit has a lowest PCA final score (-8.78). ● 4 indicators in the technical inspection unit have negative values, namely learning culture (−0.178), awareness and opacity (−0.226), preparedness (−0.332), and flexibility (−0.174). This shows that the four indicators are in a critical situation and require special attention.
13.	The phased application of STAMP, FRAM and RAG as a strategy to improve complex sociotechnical system safety.[31] Prog Nucl Energy 2021: 131 https://doi.org/10.1016/j.pnucene.202	Nuclear	Linhares *et al.*	**Objective** Analyzing the accident documents of the loss of the USS nuclear submarine using the STAMP, FRAM, and RAG methods	● Qualitative Research ● Instrument: RAG ● Accident documents were analyzed and coded on a 5-point Likert scale from "strongly disagree" to "strongly agree" ● Descriptive analysis	● STAMP, FRAM, and RAG have outputs with different levels of precision. ● STAMP and FRAM have more detailed outputs but require a lot of time and skill. RAG is a simpler and faster alternative. ● RAG focuses more on analyzing stakeholder involvement in the safety of the sociotechnical system.

No.	Article Title / Journal / DOI	Industry	Authors	Objective & Participant	Method Used to Measure Safety Resilience	Resilience Result
	0.103571					
14.	Development of a quantitative resilience model for nuclear power plants.[32] Annals Nucl Eergy 2018: 122 https://doi.org/10.1016/j.anucene.2018.08.042	Nuclear	Kim *et al.*	**Objective** Assess resilience quantitatively based on the resilience model for unforeseen situations developed by Électricité de France	● Mix-methods research ● 222 incident reports at the Fukushima nuclear power plant in 2003 – 2016 ● Indicators based on Hollnagel *et al.* (2013): Anticipation, Robustness, Adaptation, Collective Functioning, Learning Organization. ● Analysis of the relationship between resilience and resilience attributes	● There is a significant correlation between resilience and all attributes except learning organization ● Learning organization only has a significant correlation with anticipation. ● Collective functioning affects robustness and adaptation. Adaptation and robustness influence each other.
15.	Construction SMEs safety challenges in water sector in Oman.[33] Saf Sci, 2021: 136 https://doi.org/10.1016/j.ssci.2020.105156	Construction	Mawli *et al.*	**Objective** Explore the understanding of the safety of water sector construction staff in Oman **Participants** Ministries, clients, and contractors (n = 88)	● Quantitative research ● Resilience measured using PEROSH with a 5-point Likert scale ● Resilience indicator: preparedness from unexpected events and recover ability from unexpected events. ● Descriptive analysis	● The company is not prepared for unexpected events (2.5) ● The company do not easily recover from unexpected events (2.7)
16.	Assessing the relationship between organizational management factors and a resilient safety culture in a collegiate aviation program with Safety Management Systems (SMS).[34] Saf Sci, 2020: 131 https://doi.org/10.1016/j.ssci.2020.104909	Aviation	Adjekum *et al.*	**Objective** To validate a survey instrument that assesses the relationship between an RSC and 4 organizational management factors **Participants** • Aviation students, certified flight instructors, faculty, maintenance personnel, dispatch, administrative, and top management in collegiate aviation program in the US (n = 519) • Purposive sampling	● Quantitative research ● Questionnaire based on Reason's attributes of an organization with an RSC (40 items). ● Indicator: Principles, Policy, Procedures, and Practices. ● 5-point Likert scale from 1 "strongly disagree" to 5 "strongly agree" ● Multivariate analysis	● Principles, policy, procedures, and practices had a significant predictive relationship with RSC ● Policy has the highest predictive relationship, meanwhile, practices have the weakest predictive relationship with RSC. ● Procedures strongly mediated path between policies and practices. ● There was no significant causal relationship between principles and practices.
17.	Assessing Reliability and Validity of an Instrument for Measuring Resilience Safety Culture in Sociotechnical Systems.[35] Saf Health Work, 2018: 9 (3) https://doi.org/10.1016/j.shaw.2017.07.010	Petrochemical	Shirali *et al.*	**Objective** Evaluate the reliability and validity of an instrument in measuring the RSC in sociotechnical systems. **Participants** Staff members from 12 units of a petrochemical plant (n = 354).	● Quantitative Research ● Self-designed questionnaire from literature review (66 items) ● 13 Indicators: Just culture, Management of change, Learning culture, Risk assessment/management, Preparedness, Flexibility, Reporting case, Management commitment, Awareness, Safety management system,	● The results of the content validity index and content validity ratio were 0.97 and 0.83, respectively. ● The reliability of the RSC instrument, as measured by internal consistency, was found to be satisfactory (Cronbach α ¼ 0.94). ● This new instrument is valid for use in assessing RSC in sociotechnical systems, such as the petrochemical, chemical, and oil refinery industries.

No.	Article Title / Journal / DOI	Industry	Authors	Objective & Participant	Method Used to Measure Safety Resilience	Resilience Result
					Accident investigation, Involvement of staff, and Competency ● 5-point Likert scale from "strongly disagree" to "strongly agree" ● Validity and reliability analysis	
18.	Resilience Capacity Evaluation for the Safety Management System of Power Grid Enterprise Based on AHP-MEE Model.[36] Math Prob Eng, 2022 https://doi.org/10.1155/2022/8065814	Electricity	Zhang *et al.*	**Objective** Evaluate the safety management system's safety resilience capability from four basic elements: stability, redundancy, efficiency, and adaptability **Participants** Technicians, engineers, managers, administrative staff (n = 11)	● Quantitative Research ● The questionnaire was prepared based on the 4 elements of SMS theory: Stability, redundancy, efficiency, and adaptability ● Scoring using AHP concept ● Descriptive analysis	● Evaluation indicators for electric power companies are reclassified based on SMS "1438" ● The AHP-MEE combined model can be optimally implemented in the electric power industry ● Safety resilience of the sample is at level 2 (Stronger safety resilience)
19.	A consensus-based AHP for improved assessment of resilience engineering in maintenance organizations.[37] J Loss Prev Process Ind, 2017: 47 http://dx.doi.org/10.1016/j.jlp.2017.02.028	Oil and Gas	Azadeh *et al.*	**Objective** Develop valid methods to improve resilience engineering assessments. **Participant** Employees from 11 maintenance departments of Theran Gas Company (n = 99)	● Quantitative Research ● Resilience is measured using CLI: Top management commitment, just culture, culture of learning, awareness and opacity, preparedness, and flexibility. ● The questionnaire has a 6-point Likert scale (strongly disagree, disagree, slightly disagree, slightly agree, agree, strongly agree) ● Scoring using AHP ● Regression analysis.	● There is a significant relationship between RE and human-related PSFs ● Increasing RE intervention can lead to an increase in the condition of PSFs so that the number of human errors will decrease and company safety will increase.
20.	Quantitative assessment of resilience safety culture using principal components analysis and numerical taxonomy: A case study in a petrochemical plant.[38] J Loss Prev Process Ind, 2016: 40 http://dx.doi.org/10.1016/j.jlp.2016.01.007	Petrochemical	Shirali *et al.*	**Objective** Assessing the RSC of a petrochemical plant quantitatively using PCA and NT. **Participants** Employees from 12 units in a petrochemical plant (n = 312)	● Quantitative Research ● Self-constructed questionnaire (based on literature review and interview with safety experts) with the 5-point Likert scale ● 13 Indicators: Just culture, Management of change, Learning culture, Risk assessment/management, Preparedness, Flexibility, Reporting case, Management commitment, Awareness, Safety management system, Accident investigation,	● DMU6 is the best unit regarding resilience safety culture indicators with the final score of 25.960. ● DMU11 is the worst unit with the final score of 0.560 (needs a serious attention to promote safety resilience indicators).

No.	Article Title / Journal / DOI	Industry	Authors	Objective & Participant	Method Used to Measure Safety Resilience	Resilience Result
					Involvement of staff, and Competency. ● Descriptive analysis performed using PCA. Then, NT approach was used to verify and validate the results of the PCA.	
21.	Evaluation and improvement of a method for assessing HSMS from the resilience engineering perspective: A case study of an electricity distributor.[39] Saf Sci, 2011: 49 https://doi.org/10.1016/j.ssci.2010.09.017	Electricity	Saurin *et al.*	**Objective** Evaluate the HSMS assessment method using the philosophy of RE **Participants** Front-line electricians, directors, and deputy directors of the HS department (n = 120)	● Qualitative Research ● Data collection through document analysis, observation, and interview results. ● Resilience principle based on Costella *et al.* (2009): Top management commitment, learning, flexibility, and awareness. ● Evaluation based on MAHS: HSMS planning, Production processes, People management, General safety factors, Planning of performance monitoring, Feedback and learning, Results ● Descriptive analysis	● The results of the assessment identified 17 sources of resilience and 47 sources of brittleness. ● Strengths: MAHS provides information on informal processes that are not normally covered by HSMS audits. This is important in the perspective of RE, namely the ability to learn normal jobs compared to specified jobs. ● Weaknesses: This method takes a long time and requires a lot of auditors who understand RE theory.
22.	An intelligent framework for assessment and analysis of human resource from resilience engineering, motivational factors, HSE and ergonomics perspectives.[40] Saf Sci 2016: 89 http://dx.doi.org/10.1016/j.ssci.2016.06.001	Petrochemical	Azadeh *et al.*	**Objective** Assessing productivity and analysis of human resources in petrochemical plants by considering the concept of RE, motivation in the work environment, and HSE. **Participants** The staff of various departments of the plant (n = 165)	● Quantitative Research ● Resilience questionnaire based on Hollnagel (2006) and Azadeh *et al.* (2014) ● Resilience indicators: Top management commitment, Reporting culture, Learning, Preparedness, Flexibility, Awareness, Self-organization, Teamwork, Redundancy, and Fault-tolerance. ● 10-point Likert scale (1 = quite disagree, 10 = quite agree) ● Relationship analysis between RE indicators and performance (efficiency and effectiveness)	● Top management commitment has significant positive effects on efficiency. ● Top management commitment, flexibility, reporting culture, awareness, and teamwork have significant positive effects on effectiveness.

Notes: RAG = Resilience Assessment Grid, SPMS = Safety Performance Measurement Systems, TOE = Technical, Organizational, and Environmental Framework, HSE = health, safety, environment, RE = resilience engineering, AHP = analytic hierarchy process, FA = Factor Analysis, PCA = principal component analysis, WAI = work-as-imagine, WAD = work-as-done, OSH = occupational safety and health, CLI = composite leading indicator, STAMP = System-Theoretic Accident Model and Process, FRAM = Functional Resonance Analysis Method, PEROSH = Partnership for European Research in Occupational Safety and Health, RSC = Resilience Safety Culture, SMS = Safety Management Systems, NT = numerical taxonomy, HSMS = health and safety management systems, MAHS = Method for Assessing Health and Safety Management System.

Table 2 lists 13 quantitative research articles, three qualitative research articles, five semi-quantitative research articles, and one mixed-method research article. Data collection regarding resilience was carried out by filling out

questionnaires and interviews and analyzing safety-related documents. RAG questionnaires were mostly used (n = 11). This questionnaire was also heavily modified according to the sector or the researcher's needs.

The answer scale used between studies varied widely. Some used a 10-point Likert scale, a 6-point Likert scale, a 5-point Likert scale, and 3 categories of answers "Yes," "No," or "Unknown." Major articles calculated scores by calculating the average score of each question on the resilience questionnaire.

However, some articles performed calculations using the AHP concept, a tool arranging questions into hierarchies so that each question has a different value weight. A total of 13 articles only took a descriptive analysis to determine the level of resilience ability in the industry; four articles examined the relationship between overall safety resilience, resilience abilities/indicator, and other variables; two articles observed a more complicated and complex analysis by mapping the social interaction between workers; and trials of a resilience measurement instrument were carried out in three other articles.

Table 3. Detailed Article Comparison by Industry

No	Industry	Scoring Method	Highlight	Limitation
1	Health Care	Using RAG with a 5-point Likert scale	There are different number results in each dimension	• Limited number of samples • Data collection problems (such as availability for interview or field review) • There are some contextual factors, such as social interaction, that need to be explored
2	Construction	Using RAG and PEROSH	The learning dimension becomes the most concerned dimension in each article	• Limited number of samples • Data collection problems, such as availability for interview or field review
3	Maritime	Using interview-based RAG	Specifically, discussing the differences in the results of public and private sector resilience assessments	• No further information
4	Chemical	Using RAG with a 5-point Likert scale	Most activities related to monitoring, responding, and anticipating are aimed at maintaining an acceptable risk level rather than reaching the optimal situation; while, the learning potential focuses on those that contribute to the optimal situation	• Preliminary studies in Poland • Limited number of samples
5	Oil and Gas	AHP with a 6-point Likert scale	AHP can be considered as an appropriate method for resilience assessment in oil and gas	• No further information
6	Petrochemical	Different quantitative method	The interaction of each dimension inferred that the factors of top management commitment and preparedness factor need to be discussed in this industry	• Limited number of samples • Data collection problems (such as availability for interview or field review)
7	Process Industry	Tailormade Questionnaire (including just culture, flexibility, preparedness, awareness, and learning culture)	Four indicators out of six have a negative score (critical situation) in the technical inspection unit. Their score is learning culture (−0.178), awareness and opacity (−0.226), preparedness (−0.332), and flexibility (−0.174).	• Limited number of samples • Potential improvement for accurate variables for qualitative study.
8	Road Transportation	RAG	A high number of respondents answered Yes to the questions about responding with the question around alternative tasks.	• Limited number of samples
9	Electricity	Different method, mainly developing their specific model and scoring number	It is necessary to speed up the construction of emergency command centers and enhance the emergency response capabilities of enterprises to better respond to emergencies in these industries.	• Limited number of samples • Data collection is centralized only in the main office
10	Aviation	Resilient safety culture (Reason,	Procedure as mediator for all elements, policy becomes the highest	• It is recommended that the inferences drawn from this study be

		2011) with a 5-point Likert scale	number, practice the lowest.	limited to the study population and not generalized
11	Solid waste	Tailormade Questionnaire	Highlight indicators: Top management commitment, just culture, culture of learning, awareness and opacity, preparedness, flexibility	• No further information
12	Nuclear	Different method	It is possible to devise a safety management strategy that maximizes the benefits of using each of these approaches	• The studies are mainly preliminary

Notes: RAG = Resilience Assessment Grid, PEROSH = Partnership for European Research in Occupational Safety and Health, AHP = analytic hierarchy process.

Table 3 explains the 12 industries. There were similar limitations, such as limited number of samples and data collection problems in each industry. Contextual factors, such as influential social interactions in the analysis, were found in the healthcare industry. Each industry has various methods for resilience analysis. It is not uncommon for industries to choose to develop their analysis methods to suit the conditions of their respective industries.

Discussion

The SLR results showed that a mixed approach of Safety I, Safety II, and Resilience Engineering dealt with capacities for managing both the expected and unexpected events, creating a more adaptive approach to safety. This study showed that most articles used the RAG instrument (n = 11) to measure safety resilience in the workplace. Of the 11 articles, most presented a company's safety resilience profile (n = 7). The safety resilience profile found has varied results in each industry. The ability to learn and respond is the resilience ability that got the highest scores in several articles. Nonetheless, the abilities to learn and respond also got the lowest scores in two articles.[21,28]

The ability to monitor got the highest score in one article and the lowest score in two articles.[22,24,26] The ability to anticipate neither got the highest nor lowest scores in one article.[19] Most articles included were based on Resilience Engineering theory by Hollnagel *et al.*, encompassing the dimensions of Respond, Monitor, Learn, and Anticipate. The other articles highlighted alternative theoretical frameworks. This emphasizes that resilience engineering could also be explored and understood through multiple theoretical lenses beyond the approach by Hollnagel *et al.*

Most articles only used descriptive analysis to display the resilience profile and did not further explore the findings or identify suggestions for improvements a company could make. However, three articles not only presented a resilience profile but also identified opportunities for improvement in safety management.[30,34,40] Among the articles included in this study, three articles used qualitative methods to capture the subject's resilience engineering profile, showing that resilience engineering could be captured through quantitative methods and qualitative approaches.[30,39,40]

Apart from the RAG, other instruments for resilience measures were the Composite Leading Indicator (n=3), PEROSH (n=1), Safety Management System attributes (n=1), theory by Hollnagel *et al.* (2013) (n=1), Resilient Safety Culture attributes by Reason (n=1), theory by Costella *et al.* (2009) (n=1), and self-construct questionnaires from resilience's works of literature (n=3). The research results were varied for different indicators of resilience. Most analysis results were only a description of the safety resilience profile.

However, four articles further analyzed the relationship between safety resilience and other variables, such as work performance and organizational safety, as well as the relationship between each resilience indicator.[29,34,35,37] Besides, the results might also be varied due to limitations associated with minimum sample sizes in the included articles, data collection methods centralized in specific settings such as work environment, and the absence of comparable data as they represent the first study once conducted in respective areas. In short, studies on resilience have a variety of research approaches and dynamic methods for identifying the resilience profile of an industrial sector or company.

Conclusion

Although most of articles apply the resilience ability concept by Hollangel *et al.,* other articles from various industries highlight alternative theoretical frameworks for resilience engineering methods to explore and comprehend. A significant relationship is found between each resilience indicator according to several studies. Besides, an increase in safety resilience positively improves work performance and organizational safety. Further studies that display the safety

resilience profile and explore the findings in more depth need to be conducted, so that improvement opportunities could be identified for improving organizational performance.

Abbreviations

SLR: systematic literature review; PRISMA: Preferred Reporting Items for Systematic Review and Meta-Analyses; RAG: Resilience Assessment Grid; SPMS: Safety Performance Measurement Systems; TOE: Technical, Organizational, and Environmental Framework; HSE: health, safety, environment; RE: resilience engineering; AHP: analytic hierarchy process; FA: Factor Analysis; PCA: principal component analysis; WAI: work-as-imagine; WAD: work-as-done; OSH: occupational safety and health; CLI: composite leading indicator; STAMP: System-Theoretic Accident Model and Process; FRAM: Functional Resonance Analysis Method; PEROSH: Partnership for European Research in Occupational Safety and Health; RSC: Resilience Safety Culture; SMS: Safety Management Systems; NT: numerical taxonomy; HSMS: health and safety management systems.

Ethics Approval and Consent to Participate

This study is a systematic literature review that does not use specific informed consent for a specific population.

Competing Interest

The authors declare no significant competing financial, professional, or personal interests might have affected the performance or presentation of the work described in this manuscript.

Availability of Data and Materials

The first author can provide all data and materials from this study.

Authors' Contribution

MW, FL, ZD, and AMK contributed to the design and implementation of the research. AH and MSA were involved in the data analysis, while MW and FL provided supervision. MW, AMK, AH, and MSA were involved in manuscript preparation, content refinement, and administration. All the authors discussed the results and contributed to the final manuscript.

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