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A Review of the Application of FRAM and STAMP Approaches Combined with Other Methods

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ABSTRACT

When dealing with risks associated with complex sociotechnical systems, one needs to employ approaches that will make it possible to better understand the systems' complexity and analyze them more efficiently. Several approaches have been proposed and in the recent literature, the System-Theoretic Accident Model and Processes (STAMP) and Functional Resonance Analysis Method (FRAM) stand out. These have been applied both separately and integrated with other methods for risk analysis. This study aims to provide an overview of the literature related to the application of FRAM and STAMP integrated with other methods. Papers from various scientific resources, including Scopus, IEEE, Compendex and INSPEC, Google Scholar, and Espace ÉTS from 2004 to 2021, in English, were consulted. The keywords used to narrow our search were FRAM, STAMP, STPA, and risk analysis. The results show that FRAM and STAMP have been used in combination with other methods such as fuzzy logic, Monte Carlo Simulation, bow tie, and model checking. Their combination with other methods has enhanced their efficiency and capability in risk analysis and provides better and more precise outcomes for some specific contexts of study. These combined proposed approaches have been applied and validated for specific contexts in specific studies. Therefore, the generalization and validation of the combined methods in different contexts could be an outlook for future studies.

Keywords: Combined approach, FRAM, STAMP, STPA, Risk analysis

INTRODUCTION

Systems safety has always been an essential part of manufacturing. Over the years, the proposed methods for systems' risk analysis have evolved both in response to the evolution of the systems and to address the new challenges and risks these systems face (Grabbe et al., 2020). Different methods, from classical to systemic, have been introduced over the past decades, and their usefulness and efficiency have been examined and evaluated within several contexts of study (Grabbe et al., 2020). As systems evolved, experts developed the concept of sociotechnical system, and findings have showed that classical methods are unable to provide adequate risk analysis for such systems (Adriaensen et al., 2019).

Therefore, finding appropriate approaches that provide a comprehensive analysis of the studied system has been an interesting subject for many

researchers in recent decades. Among different approaches introduced by researchers, a considerable number of studies have been devoted to the application of Functional Resonance Analysis Method (FRAM) (Hollnagel, 2012) and System-Theoretic Accident Model and Process (STAMP) (Leveson, 2011) in different contexts. These methods look at the system from a systemic and non-linear perspective to identify component interactions that might lead to a hazard. By providing a good understanding of the system and its components, they enable the analyst to explore variabilities and hazardous interactions within the complex system.

However, even if many studies proved the worthiness of these methods in risk analysis, some researchers introduced novel approaches by combining FRAM (Pardo-Ferreira et al., 2019) or STAMP (Patriarca et al., 2022) with other methods. They found that when FRAM or STAMP were applied alone, there was a gap between the expected and the obtained result. Moreover, some analyses needed quantified results to achieve more precise results for a specific context. These innovations improve the obtained results and enhance these methods' capabilities. This study aims to provide a review of the methods that have been combined with FRAM and STAMP. The results show that their combination with other methods improved the analysis within the study's specific context. Many combinations have been proposed of other methods with FRAM and STAMP, but only one study considers a combination of these two methods with each other. Applying FRAM and STAMP is a novel combination, which needs further study both to develop it and examine it in various specific contexts, and to validate its efficiency.

The remainder of this study is structured as follows. Section 2 discusses the methodology applied to retrieve the related studies. This is followed by the results in Section 3. Section 4 discusses the results and draws conclusions.

METHODOLOGY

To retrieve the related studies, various scientific databases, including Scopus, IEEE, Compendex and INSPEC, Google Scholar, and Espace ÉTS from 2004 to 2022, in English, were consulted. The keywords used to narrow the number of results were risk analysis, FRAM, STAMP, STPA, and combined approach. The papers were chosen by their title, and then for screening, abstracts were studied to verify their relevance to the study's objective. Finally, a brief review of the obtained papers through discussed methodology was presented in two tables, one for FRAM and one for STAMP, noting the objective of the study, applied methods, results of the application of the proposed method, and the domain of study. The results are shown in the next section.

RESULTS

By applying the methodology discussed in Section 2, we retrieved 59 papers. Thirty-three of them studied the application of FRAM combined with other methods (Table 1). The other 26 investigated the application of STAMP (mostly STPA) with other methods (Table 2). The proposed methods go by different names, such as integrated, combined, hybrid, development, and

Table 1. FRAM application combined with other methods.

Author & Year	Main Objective	Applied Methods	Results	Domain
(Zheng and Tian, 2015)	Application of finite state machine and model checker to formally present FRAM.	FRAM + finite state machine (FSM) and model checker NuSMV	Application of proposed methods with FRAM gave a new perspective about accidents and complemented the understanding of the system.	Herald of Free Enterprise car ferry accident
(Yang and Tian, 2015)	Application of FRAM and the Model-Based Safety Assessment (MBSA) checking model to identify potential hazards.	FRAM + MBSA -model checking	The combined approach was useful in verifying the FRAM analysis model by model checking and ensuring whether the safety requirements were upheld or needed further analysis.	Landing process of an airplane
(Rosa et al., 2015)	Analyze risks through the application of FRAM and the AHP.	FRAM + analytic hierarchy process (AHP)	The combined application provided a new perspective of the system and a better understanding of critical functions.	Construction
(Duan et al., 2015)	Develop FRAM by bridging theory and practice through model checking.	FRAM + model checking	The proposed approach refined the results by redefining and categorizing couplings. It helped to identify more couplings and provide a better understanding of the system's behavior.	Aviation (air accident)
(Hirose et al., 2016)	Analyze the feasibility of procedures for highly automated systems.	FRAM + Fuzzy CREAM	The proposed method was not only useful for the analysis of accidents but also for the pre-analysis of the safety of documented procedures.	Flight-deck procedures (Cali airport air crash accident)
(Zheng et al., 2016)	Propose an approach to refine operation guidelines and to reduce the risk of producing unqualified products.	FRAM + Finite State Machine (FSM)+ model checker SPIN	The application of the proposed approach showed its feasibility and effectiveness in refining process guidelines.	Aero engine blade forging (manufacturing)
(Patriarca et al., 2017b)	Propose a semi-quantitative FRAM model based on the Monte Carlo Simulation.	FRAM + Monte Carlo Simulation (MCS)	The proposed approach helped highlight the most critical functions and facilitated the understanding of analysis through the provision of numerical results.	Air Traffic Management (ATM)
(Patriarca et al., 2017a)	Use Abstraction Hierarchy (AH) to provide a detailed representation of functions at a different level.	FRAM + Abstraction Hierarchy (AH)	The proposed approach provided an Abstraction/Agency framework presenting the studied system in a structured and systemic manner. The multilayer presentation of the system enhanced the knowledge of the system.	Railway domain

(Continued)

Table 1. Continued

Author & Year	Main Objective	Applied Methods	Results	Domain
(Bellini et al., 2017)	Investigate and quantify resilience enhancement of Urban Transport System equipped with Internet of Everything (IoE).	FRAM + Network analysis techniques	The study concluded that the variability rate would be enhanced with the deployment of IoE.	Urban Transport System (UTS)
(Yang et al., 2017)	Analyze and model (Minimum Safe Altitude Warning) MSAW-in-ATM system, formalizing variabilities and interactions.	FRAM + formal verification tool SPIN	The results showed that achieving a successful design is possible through a comprehensive analysis of the system safety within system development.	Air Traffic Management
(De Felice et al., 2017)	Develop a novel approach to Human Reliability Analysis (HRA) that evaluates the variability of the human error probability.	FRAM + HRA	The method could evaluate quantitively the probability of human functions and their effect on downstream functions.	Petrochemical company
(Jensen and Aven, 2017)	Propose a new hazard identification method by applying Anticipatory Failure Determination and FRAM.	FRAM + Anticipatory Failure Determination (AFD)	The combined approach provided creative methods for inventing potential hazards in complex systems.	Lifting operation
(Toda et al., 2018)	The application of four keywords of STPA analysis in the FRAM method.	FRAM + STPA	The proposed approach was suitable for risk analysis in the concept and design phase. It could find more hazards compared to solely applying STPA.	Railroad crossing, Car lane changing
(Lee and Chung, 2018)	Propose a new FRAM-based approach to improve the resolution of crew interactions.	FRAM + human-system interaction (HSI)	The proposed approach assisted in analyzing the interaction of human and systems better and suggested critical parts at the HIS level to be considered in the strategy for variability management.	Maritime domain
(Riccardo et al., 2018)	Enhance the strength of FRAM-based analyses through the application of the Resilience Analysis Matrix (RAM).	FRAM + RAM	While FRAM is a powerful method in the variability analysis of operational scenarios, RAM provided a two-dimensional representation of couplings.	SkyWest Flight 5569 and USAir Flight 1493 accident

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Table 1. Continued

Author & Year	Main Objective	Applied Methods	Results	Domain
(Sekeľová and Lališ, 2019)	Apply a Resilience Assessment Grid (RAG) in aircraft components production to propose an approach specific to aviation.	Resilience Assessment Grid (RAG) + FRAM	The approach provided a model of a managed change process. It also helped develop better safety awareness and increase the organization's resilience performance.	Aircraft components production
(Slim and Nadeau, 2019)	Improve the descriptive FRAM results in the quantitative outcomes by integrating fuzzy logic.	FRAM + Fuzzy logic	The proposed approach provided a representation of the outcomes in numeric format and a comprehensive representation of potential performance variabilities.	Aircraft on-ground de-icing operations
(Li et al., 2019)	Integrate Accident Causation Analysis and Taxonomy (ACAT) with FRAM model to propose a closed-loop analysis method.	FRAM + Accident Causation Analysis and Taxonomy (ACAT)	When applying the hybrid method, more functional constraints and factors that contribute to accidents could be found. It also provided more details that helped to understand systems even though its application was more complicated than when solely applying ACAT or FRAM.	Opening a valve on a gas pipeline - Coal shearer process
(Yu et al., 2020)	Propose a FRAM-based framework to help to overcome the dependency on expert elicitation for systemic hazard identification.	FRAM + Human performance model (CREAM) + equipment performance model	The proposed approach provides a framework to aggregate the upstream variabilities quantitatively and proactively simulates the functions' interaction.	Process industries (Methyl methacrylate (MMA) batch polymerization process)
(Eljaoued et al., 2020)	Propose a qualitative-quantitative approach to risk analysis.	FRAM + Graph theory	The use of graph theory provided a quantitative assessment of the functions' interactions and evaluates their effect on functions' variability.	A simulation of crisis organization
(Hirose and Sawaragi, 2020)	Develop a tool to validate and verify safety based on the FRAM model.	FRAM + cellular automaton	The extended FRAM approach is helpful in providing insights into experienced workers' operations characteristics and identification of critical points for safety management.	Steel production line
(Falegnami et al., 2020)	Represent the FRAM model in a multi-layer network.	FRAM + Network theory	The combined method made it possible to interpret the FRAM model in multilayer networks that could enable analysts to prioritize critical functions.	Industrial plant (A power-tool accessory production plant)

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Table 1. Continued

Author & Year	Main Objective	Applied Methods	Results	Domain
(França et al., 2020)	Develop an approach to identify complexity level and critical human factors.	FRAM + AHP	The proposed approach made it possible to model the "work as done" properly to identify critical functions and worker's behavior that might be ignored in procedures.	Offshore drilling systems
(Bellini et al., 2020)	Propose a method to quantify FRAM results.	Q-FRAM	The results were obtained with a robust and fast-forward method in a practical way and provided a good insight into the system's status for decision-makers.	H2020-RESOLUTE pilot definition
(Slim and Nadeau, 2020)	Improve the size of rules and classify outcomes for the use of fuzzy logic combined with FRAM.	FRAM + rough sets/fuzzy logic	The number of rules was decreased considerably, and it was suitable especially for decision making regarding uncertain and incomplete data.	Aviation (Aircraft on-ground de-icing operations)
(Yu et al., 2021)	Propose a data-driven approach to provide quantitative results of functions' couplings.	FRAM + Association rule mining	The application of association rule mining provided quantitative metrics for functions couplings. It was also helpful in identifying the path that leads to hazard.	Polymerization process (process industry)
(Alboghobeish and Shirali, 2021)	Identify and prioritize emerging risks through an integrated application of FRAM and an AHP.	FRAM + analytical hierarchy process (AHP)	The integrated approach was useful for risk analysis and identifying emerging risks based on "work as done", not "work as imagined".	Water reservoirs management in agriculture
(Salehi et al., 2021)	Propose a dynamic FRAM-based tool for variability analysis.	DynaFRAM (programming FRAM via Python programming language)	DynaFRAM could capture the different variabilities' characteristics and facilitate understanding and analyzing complex operations' variability.	Healthcare case study
(de Souza et al., 2021)	Apply a layered FRAM to analyze work as done in HVAC system maintenance.	Layered FRAM	The proposed approach provided a better perspective of functions, decreased the analysis complexity by dividing the analysis into layers, and facilitated model analysis.	Maintenance of heating, ventilation, and air-conditioning (HVAC) systems
(Zinetullina et al., 2021)	Quantify the FRAM's analyzing resilience for a chemical process.	FRAM + Dynamic Bayesian Network (DBN)	The proposed approach provided a rigorous quantitative analysis of the system and assessed resilience in both probabilistic and temporal aspects.	Chemical process systems (a separator of an acid gas sweetening unit)

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Table 1. Continued

Author & Year	Main Objective	Applied Methods	Results	Domain
(Kim and Yoon, 2021)	Develop an approach to quantify FRAM results and variability propagation.	Rule-based FRAM	The proposed method was useful for assessing potential risks in a crisis and supporting decision-makers in their response to a crisis.	Emergency response system for infectious disease (COVID-19)
(Huang et al., 2022)	Formulate the variability mechanism of FRAM through the risk pulse theory.	FRAM + N-K model	The proposed approach provided quantitative results for variabilities; however, the historical statistical frequency of every risk factor was required.	An accident in railway hazardous goods transportation
(Liu et al., 2022)	Evaluate the safety of operating procedures of medical equipment.	FRAM–Moran's I and CREAM	The proposed approach provided a systematic perspective regarding the ergonomic reliability of medical equipment.	Operation procedure of a medical equipment

Table 2. The application of STAMP combined with other methods.

Author & Year	Main Objective	Applied Methods	Results	Domain
(Colley and Butler, 2013)	Propose an approach to hazard analysis for system requirements that are captured as monitored, controlled, mode, and commanded phenomena.	STPA + Event-B	Event-B applied with STPA helped provide a formal representation of safety constraints as "invariants" or "guards" in the formal model.	Washing machine system
(Mason-Blakley et al., 2014)	Propose a combined approach of FMEA and STPA for hazard analysis of an information system.	STPA + Failure Modes and Effects Analysis (FMEA) = Information Systems Hazard analysis (ISHA)	The combined approach addressed the weakness of the FMEA method in the qualitative aspect that compromises reproducibility and improves the obtained results.	Clinical Information Technology (CIT)
(Abdulkhaleq et al., 2015)	Develop an STPA-based approach for comprehensive safety engineering of software.	STPA + softw-are testing and model checking approach	The proposed approach could be integrated into software development processes. It was helpful in identifying unsafe control action and performing analysis in system levels. It improved workflow and communications between software and safety engineers.	A software

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Table 2. Continued

Author & Year	Main Objective	Applied Methods	Results	Domain
(Montes, 2016)	Product testing through the application of STPA to refine the human controllers' analysis.	STPA + Refined Controller (RC)	The approach improved the results and identified additional unsafe behaviors that might affect inherent system safety.	The U.S. Air Force product
(Johnson, 2016)	Introduce an STPA extension called STPA-Coordination.	STPA + unsafe coordination analyses	The extended approach helped to identify more hazardous coordination scenarios and recommendations.	Unmanned aircraft systems
(France, 2017)	Propose a new approach to analyze the role of humans in complex automated systems.	STPA + Engineering for Humans (STPA-Engineering)	The approach guided analysts in identifying casual scenarios related to human interactions with automation and understanding why an unsafe behavior appears appropriate in an operational context. It also provided a special dialogue framework for communicating between human factors experts and engineers from other fields. It was useful in comparing the effect of human behaviors on different system designs.	Automated driving system (Automated Parking Assist)
(Thapaliya and Kwon, 2017)	Propose an integrated approach for safety analysis from the perspective of reliability and control theory.	STPA as revolutionary safety method + results of the application of hazard and operability study (HAZOP), failure mode and effect analysis (FMEA), and fault tree analysis (FTA) as evolutionary safety methods	The integrated approach was shown to be more comprehensive than the separate application of risk analysis methods.	Green Line Metro System (train control system)
(Howard et al., 2017)	Propose an approach for safety and security risk analysis of cyber-physical systems.	STPA + Event-B	The inclusion of Event-B to STPA analysis provided integrated critical requirements that are represented formally (not simple text) as variants, guards, etc. These requirements could then be mitigated.	Cyber-physical systems
(Sousa et al., 2017)	Apply STAMP and Lean philosophy to eliminate waste in a production system.	STAMP + Lean philosophy	The combined application of Lean and STAMP provided more information through a better representation of the organizational structure of the production system compared to applying Lean alone for waste elimination.	Production system

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Table 2. Continued

Author & Year	Main Objective	Applied Methods	Results	Domain
(Friedberg et al., 2017)	Propose a novel approach to safety and security analysis of cyber-physical systems.	STPA-SafeSec	The proposed approach provided a description of a generic component layer diagram and a generic casual factors diagram in the security domain. It could provide an in-depth security analysis of the critical system components.	Power grid (synchronous-islanding)
(Dakwat and Villani, 2018)	Provide a formal and unambiguous representation of the studied system analysis and identified hazards using STPA.	STPA + model checking	Combining STPA and model checking improved the results and knowledge of the system being designed. It was also consistent with the design changes suggested to deal with identified safety constraints in the STPA analysis results.	Robotic flight simulator
(Wang and Wagner, 2018)	Propose an approach to agile development that addresses the lack of appropriate safety analysis and verification methods.	STPA + Behavior Driven Development (BDD)	The preliminary results showed that the combined STPA-BDD is capable of providing effective communications between developers and business analysts.	Agile software development
(Joung et al., 2018)	Develop an approach to risk and hazard identification of a Dynamic Positioning (DP) and mooring system in design and operation.	STPA + Hazard identification study (HAZID)	A comprehensive hazard analysis through the application of multiple hazard identification methods was recommended to benefit from each method's capability and compensate for their weaknesses.	mooring system in Arctic condition
(Torkildson et al., 2019)	Improve co-analysis of safety and security by applying threat modeling approaches as a complementary strategy.	STPA-sec + Threat modeling approaches (Misuse of cases, data flow diagram, attack tree, Business Process Modelling Notation (BPMN))	Among different approaches, the data flow diagram showed better results in combination with STPA-sec for the specific case study; however, other threat approaches could complement STPA-sec from different aspects. It also helped identify more unsafe control actions than if STPA-sec had been solely applied.	Autonomous boat
(Hirata and Nadjm-Tehrani, 2019)	Investigate the combination of STPA and GSN for a safety risk analysis approach.	STPA + Goal Structuring Notation (GSN)	The use of GSN in combination with STPA was feasible for supporting certification decisions. This approach improved the safety engineers'	The train door controller

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Table 2. Continued

Author & Year	Main Objective	Applied Methods	Results	Domain
			communication and was useful in importing the argumentation structure from the STPA method. It was a useful generic approach for documenting quality insurance cases in any system that applies STPA and GSN for risk analysis.	
(Silva Castilho, 2019)	Propose an integrated hazard analysis for Safety Management Systems (SMS).	STPA + SMS = Active STPA	The integrated approach enabled the proactive identification of leading indicators that showed risk increments. It also provided good qualitative information and helped to manage hazards in an SMS.	Aviation
(Bensaci et al., 2020)	Apply a combination of STPA and Bowtie for safety assessments of robot collaborations for a better comparison of different controls.	STPA + Bowtie	The combined approach provided detailed hazard identification and risk classification that improved STPA outcomes and facilitated decision-making on finding the most suitable approaches.	Multi-robot systems
(Souza et al., 2020)	Propose a method for simulation and formal verification of system models through the combination of STPA and SysML modeling activities.	STPA + Systems Modeling Language (SysML) modeling activities	The combined approach was helpful to structure STPA analysis with clarification and clear specifications of assumptions, requirements, system boundaries, and their interactions through the application of SysML diagrams.	An automatic door system
(Dunsford and Chatzimichailidou, 2020)	Embed the STPA application into CSM-RA as a supplement to ensure the understanding of safety requirements.	STPA + Common Safety Method for Risk Evaluation and Assessment (CSM-RA)	The use of STPA with CSM-RA produced a powerful safety assessment process and saved money and time. However, there are still challenges regarding the limitation of CSM-RA framework bounds.	The rail sector
(de Souza et al., 2020)	Apply STPA extension with threat model ((STRIDE= Spoofing, Tampering, Repudiation, Information Disclosure, Denial of Service, and Elevation of Privilege) for a	STPA + threat model	The proposed approach provided a more complete analysis and identified loss scenarios.	Electronic voting system by smartphone

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Table 2. Continued

Author & Year	Main Objective	Applied Methods	Results	Domain
	simultaneous safety and security risk analysis of system developments in the concept stage.			
(Carreras Guzman et al., 2021)	Compare a novel extension of STPA and Uncontrolled Flows of Information and Energy (UFoI-E) in terms of differences and potential for combination by applying it to the same case study.	STPA-Extension (both safety and security analysis) + Uncontrolled Flows of Information and Energy (UFoI-E)	Both methods were useful for safety and security risk assessment. However, a combination of results obtained by both methods provided higher and more reliable levels of result completeness.	Cyber-physical systems-Case study: ReVolt, a conceptual autonomous ship
(Liew et al., 2021)	Propose a safety and security (S&S) approach to use STPA for cyber-physical systems.	STPA (for safety and security) + 8 Matrix Diagram presentation	The methods enabled analysts to oversee the correlation between safety and security.	Cloud-based monitoring and control system for residential energy storage systems
(Xing et al., 2021)	Introduce FSM to complement risk analysis results of STPA application.	STPA + Finite State Machine (FSM)	The combination of STPA and FSM compensated for the weaknesses of the STPA method in the risk analysis of high-level autonomous vehicles, with several automated modes and functions. It also provided more details and found more hazardous events to generate testing scenarios.	Autonomous Vehicles
(Dghaym et al., 2021)	Develop an approach to identify and analyze the mission requirements for autonomous missions in autonomous systems.	STPA + formal modeling	The proposed approach continuously reviewed factors that might affect formal modeling. On the other hand, formal modeling could improve system requirements by identifying new requirements, removing ambiguity and ensuring the consistency of the requirements.	Unmanned Surface Vehicle
(Ge et al., 2022)	Proposing a new approach for risk analysis based on Systems-Theoretic Accident Model and Processes (STAMP) and	STAMP + Risk Management Framework (RMF)	The proposed approach was powerful in providing a good explanation of the accident. It is a feasible approach for accident analysis.	Tianjin Port fire and explosion accident

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Table 2. Continued

Author & Year	Main Objective	Applied Methods	Results	Domain
	Risk Management Framework (RMF) fundamentals called Interaction Theory of Hazard-Target System (ITHTS), and proposing a new systemic accident analysis method of work systems (SAAMWS) since ITHTS cannot be applied directly to accident analysis.			
(Duan, 2022)	Formalize the results of STPA application by integrating it with model-based systems engineering (MBSE)	STPA + model-based systems engineering (MBSE)	The quantification of the outcome obtained by the proposed method showed that it is effective and feasible for the safety and risk analysis of the system designs. It linked system development and safety analysis.	Autonomous Vehicle (autonomous emergency braking system)

extended. For this study, these are considered as the same. Also, these approaches have been applied in different domains such as software development, cyber-physical systems, rail transportation, process industry, manufacturing, construction, and aviation. Aviation is where the most references were found.

DISCUSSION AND CONCLUSION

FRAM and STAMP were introduced to academia and industry about 20 years ago. Since then, a considerable number of studies have been devoted to the application of a combination of one of these methods with other methods, which demonstrates the significant contribution these methods have to offer in risk analysis regarding a comprehensive understanding of the studied system (Riccardo et al., 2018, Patriarca et al., 2022). The FRAM and STAMP methods have been applied in various contexts proving they can be applied in different sociotechnical systems. They have also been applied with other methods in various contexts. The results of this review show that the proposed approaches are more effective combined with other methods than when used alone. They benefit analysts through the provision of a comprehensive and detailed perspective of the studied system. In addition, some proposed approaches provided quantified results for better result comparisons and provided a good insight into the studied system for decision-makers. This combined approach was often used for a specific context, and its application

to other contexts would require further research. Among the different methods studied, the combined application of FRAM and STAMP was studied in only one paper (Toda et al., 2018). Regarding the dynamic characteristics of complex sociotechnical systems, combining the application of both FRAM and STAMP with other methods, there is still room for improvement. Nevertheless, it is a promising development for risk analysis (de Linhares et al., 2021).

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