REVIEW ARTICLE

Application of System Theoretic Accident Model and Processes (STAMP) in Healthcare Settings: A Scoping Review

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ABSTRACT

The healthcare industry has seen a rise in adverse events and system failures, highlighting the need for comprehensive safety analysis methods. The System Theoretic Accident Model and Processes (STAMP) offers a systems-based approach to understanding and mitigating complex interactions leading to failures. Despite its application in various industries, there is a gap in the literature regarding the extent of its use in healthcare, including its benefits and limitations. This scoping review investigates the application of STAMP in various medical departments, using the PRISMA-ScR methodology, to identify relevant studies in Scopus, PubMed, and ScienceDirect databases. Nine studies from radiology, cardiology, and other departments were identified, they reported the benefits of using STAMP, such as its ability to uncover system flaws and suggest improvements beyond traditional root-cause methods. They also highlighted several disadvantages, including potential biases and limited level of detail about specific failures. The findings offer valuable insights for researchers and healthcare professionals, indicating that STAMP is a valuable tool for enhancing patient safety and system reliability.

INTRODUCTION

Risk assessment methods including Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA) have often been used to identify and mitigate hazards and failures in many workplace settings. The application of these methods has enabled the causes and factors of adverse events to be examined, helping prevent such events from reoccurring in the future (Lundberg et al., 2009) However, as systems in many workplaces have become more complex, there is a need for more advanced tools. One such tool is the System Theoretic Accident Model and Processes (STAMP), which uses system theory and thinking to analyse complex interactions that result in failures or loss (Leveson, 2011). Unlike traditional methods that focus on identifying root causes, STAMP takes a broader view by considering accident causation as the result of system-wide interactions, making it suitable for addressing complex systems such as healthcare.

Although other advanced methods such as AcciMap and Safety Occurrence Analysis Methodology (SOAM) have been developed to also address such complexities, STAMP is gaining recognition for use in safety-critical industries like healthcare (Allison et al., 2017). For example, STAMP provides more detailed insights than AcciMap about the interactions within complex systems, including how decisions and controls at different levels contribute to safety (Salmon, Cornelissen, & Trotter, 2012). Similarly, unlike SOAM, STAMP is able to address safety issues associated with emergent phenomena that often involve non-linear interactions between different system components (Arnold, 2019).

Within the healthcare sector, STAMP has been shown to benefit healthcare settings by offering a more comprehensive analysis of systemic factors, leading to more effective interventions (Canham, 2018). Furthermore, STAMP can be useful for ensuring efficient and reliable management of healthcare systems (Yoshida, 2021). However, little is known about the extent to which STAMP has been applied in healthcare and reported in literature, for example which departments have utilised the method, as well as the advantages and disadvantages found. In light of this gap in the literature, a scoping review was carried out with the aim to identify the healthcare departments that have used STAMP and synthesise information about their reported advantages and disadvantages. In doing so, the scoping review would provide valuable insights to researchers and practitioners planning to apply or adopt STAMP.

MATERIALS AND METHODS

To achieve its objective, the scoping review was carried out according to the five-step framework developed by Arksey and O'Malley (2005) and refined by Levac et al. (2010): (i) identifying research questions, (ii) identifying relevant studies, (iii) selection of study, (iv) data charting, and (v) collating, summarizing, and reporting results. Furthermore, the scoping review was reported according

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to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) (Shaw et al., 2021). Relevant peer-reviewed papers were searched from 2004, the year STAMP was first introduced, until 2022, when this study was conducted, using three online databases: Scopus, PubMed, and ScienceDirect. Various search keywords, along with similarly meaning terms and Boolean Operators including AND, OR and parentheses, were used to identify related studies. The keywords used were (application OR utilization OR employment OR practice OR usage OR adoption OR investigation OR integrate) AND ('system theoretic accident model processes' OR 'system theoretic process analysis' OR 'causal analysis based on system theory') AND (healthcare OR hospital OR clinic OR infirmary OR medical centre OR medical OR medicine).

To be included in this scoping review, each article underwent a screening process, starting by reviewing titles and abstracts, followed by a full-text review. Only articles written in English, published in peer-reviewed journals, and utilising STAMP in healthcare were included in this study. On the other hand, review articles such as narrative, scoping, or systematic reviews were excluded, as the aim for this study was limited to original research articles. To ensure the screening reliability, 20 abstracts were independently reviewed by both authors, with only three disagreements in the outcome that were then resolved through consensus. After the full-text review, data was extracted from the selected papers according to the following data items: author, year of publication, medical department, data collection method, reported advantages, and reported disadvantages.

RESULTS

As indicated by the PRISMA-ScR diagram in Figure 1, a total of 980 articles were identified in the initial search: 22 from Scopus, 373 from PubMed, and 585 from ScienceDirect. 463 duplicate articles were removed before the screening process. The remaining 517 articles were screened based on their titles and abstracts; consequently, 501 articles were excluded and 16 articles were included for the next screening process. The full text of the 16 articles were examined according to the inclusion and exclusion criteria. Two articles were excluded due to restricted access or limited institutional resources, while five others were omitted because they only mentioned STAMP briefly without directly applying its theory. Lastly, 9 articles underwent qualitative synthesis, with data extracted and summarised in Table 1.

Data Collection Method

Several methods were utilized in the included articles, with observation being the most frequently applied as it was used in six studies. One possible advantage of using observation over other methods is its ability to capture and describe various aspects of the system, including subjects' behaviours, interactions, and contextual factors. The second most frequently applied method was focus group discussion, followed by document review, interviews, case study, and survey. This may be due to the time required to process survey data, potential low response rates, and the difficulty of using questionnaires to capture the complex, system-wide information required for STAMP analysis (Jones et al., 2013).

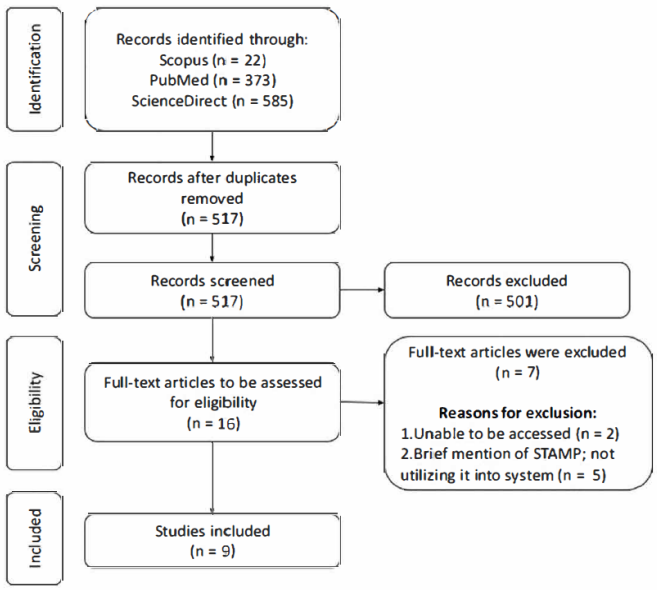

Figure 1: Flow Diagram of Articles Selection based on PRISMA-ScR Flow Diagram

Medical Department Applying STAMP

As indicated in Figure 2, departments applying STAMP to analyse their systems were identified, with Radiology having the highest reported usage, appearing in three articles (33%). This was followed by Anaesthesiology at 22%, while the remaining five departments—Cardiology, Endocrinology, Pharmacy, and Neonatal Intensive Care Unit (NICU)—each had a reported usage rate of 11%.

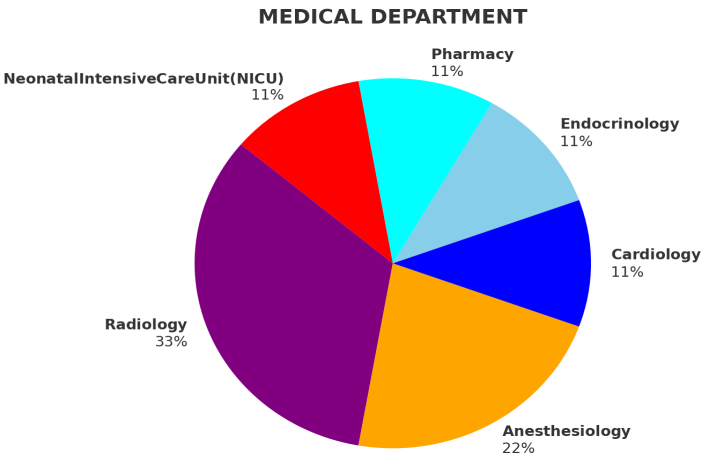

Figure 2: Medical Department Applying STAMP

Table 1: Summary of Advantages and Disadvantages of STAMP Application in Healthcare

No	Author	Year of Publication	Medical Department	Data Collection Method	Reported Advantages	Reported Disadvantages
1	Leveson et al.	2020	Cardiology	Observation	- Able to identify the general weaknesses in the control measures employed at the hospital - Able to generate systemic recommendation that current root cause analysis might sometimes overlook	Not reported
2	Silvis-Cividjian et al.	2020	Radiology	Document review, observation	- Require short time to obtain list of potential hazards - STAMP is better in term of effectiveness than HFMEA - Able to identify subtle and unexplored unsafe conditions	Does not provide a detailed description of hazard
3	Bas	2020	Endocrinology	Observation	- Consider more type of accidents and hazard causes - More effective compared to Fault Tree Analysis (FTA) and Failure Modes and Effect Analysis (FMEA)	Not reported
4	Bargal et al.	2018	Pharmacy	Focus group discussion, survey	- Helped identify important safety risks and recommend controls to mitigate these risks - Focus on system redesign rather than individual blame	- Challenging to understand - Time consuming - Less familiar
5	Patriarca et al.	2019	Anesthesiology	Focus group discussion, interview	- Reveals more hazard and potential failure in system	Mainly applied for academic context only
6	Yamaguchi & Thomas	2019	Radiology	Observation	- More effective to conduct hazard analysis for medical equipment - STAMP identified a potential and broader set of causes compared to FMEA	Not reported
7	Kaya	2021	Neonatal Intensive Care Unit (NICU)	Document review, interview, focus group discussion	- Help identify unsafe control actions and reveal more scenarios - Develop safety recommendations - User friendly and well-structured - STAMP provides a better understanding of the system to be assessed compared to FRAM	- Difficulties when building control structure - Not widely used in healthcare
8	Pawlicki et al.	2016	Radiology	Observation	- STAMP procedures are generalizable to all aspects of radiation oncology for analysing new and existing process	There could be hazards that are unidentified
9	Samost-Williams & Nanji	2020	Anesthesiology	Observation, case study	- Can be used in a variety of settings to help improve patient safety by identifying areas of highest risk to target in quality improvement initiatives	STAMP may be biased

Radiology is one of the most complex hospital departments, operating high-technology machines essential to diagnostic care. Atwal et al. (2017) reported that the workload per radiologist has consistently increased, while the number of radiologists hired has declined. Additionally, Radiology departments often operate 24/7 to meet demand. Although accidents in Radiology are less frequently reported, they do occur. Tarkiainen et al. (2020) highlighted that adult patients represent the highest frequency of cases involving excessive radiation exposure during CT procedures. Researchers have leveraged STAMP to investigate these

issues, applying it to identify root causes and contributing factors.

Meanwhile, STAMP was applied equally across the departments with the least frequent application—NICU, Emergency, Pharmacy, and Endocrinology—each at 10%. Greater consideration is needed for STAMP's application in these departments, particularly in high-risk settings like the Emergency Department (ED). Although only one study examined the ED, Amaniyan et al. (2019) reported that this department carries a high risk of patient safety incidents. The ED is one of the most demanding environments within healthcare institutions, with continuous patient flow, heavy workload, and the need to manage patients with varying conditions and severity levels (Sartini et al., 2022). Ineffective management of these challenges can lead to excessive labour demands, healthcare worker burnout, and a greater likelihood of safety incidents. These factors suggest that future studies could explore STAMP's potential to manage complex safety issues in such critical areas.

Reported Advantages

Six reported advantages were extracted from all included articles, as presented in Table 2. Firstly, STAMP effectively identifies hazards and unsafe control actions (UCAs), along with their causes. The articles highlighted that STAMP is effective for hazard identification and analysis (Bas, 2020; Patriarca et al., 2019; Yamaguchi & Thomas, 2019). Moreover, the articles suggested that STAMP can evaluate and improve control measures (Kaya, 2021; Leveson et al., 2020). These views are also shared by studies in other industries, such as nuclear power and transportation (Ahmad et al., 2021; Jung et al., 2022).

The second reported advantage is that STAMP aids in developing recommendations to reduce accident risks. Identifying UCA is only the first step; actionable solutions are needed to mitigate hazards. The articles suggested that solutions generated by STAMP are more systemic than those from root cause analysis (Leveson et al., 2020). Additionally, STAMP facilitates solutions more likely to target the highest risks for quality improvement (Samost-Williams & Nanji, 2020). This observation was also noted by Hamim et al. (2022) in the context of rail-level crossing accidents, where STAMP produced numerous recommendations when combined with other analysis tools.

Thirdly, STAMP was reported by the articles as being user-friendly and adaptable due to its straightforward design and structure. Kaya (2021) described STAMP as being easy to use due to its structured approach, which highlights its accessibility. Consequently, multidisciplinary teams, including those unfamiliar with advanced risk analysis methodologies, can effectively identify risks and develop safety recommendations. By contrast, Underwood et al. (2016) reported that first-time users from aviation industry faced difficulties using STAMP, this difference possibly due to less training and a less structured guideline than those in Kaya's study.

The fourth reported advantage of STAMP is related to its efficiency. Silvis-Cividjian et al. (2020) suggested that STAMP can be relatively quick in determining the potential hazards in a healthcare system. This means that small teams can conduct efficient and effective hazard analyses in complex settings like healthcare. Furthermore, due to its structured approach, STAMP can be proactively applied in the early phases of system design. However, this would depend on the users' familiarity with STAMP, as indicated by Underwood et al. (2016) in their study with aviation users.

Table 2: Summary of Reported Advantages of STAMP in Healthcare Applications

No	Reported Advantages	Author
1	STAMP is able to identify the UCAs along with its causes	Bargal et al. (2018), Bas (2020), Kaya (2021), Leveson et al. (2020), Patriarca et al. (2019), Samost-Williams & Nanji (2020), Silvis-Cividjian et al. (2020), and Yamaguchi & Thomas (2019)
2	STAMP is able to generate highly effective recommendations to reduce UCA risk	Bargal et al. (2018), Kaya (2021), Leveson et al. (2020), and Samost-Williams and Nanji (2020)
3	STAMP is user-friendly and adaptable	Kaya (2021) and Pawlicki et al. (2016)
4	STAMP requires a short time to obtain a list of potential hazards	Silvis-Cividjian et al. (2020)
5	STAMP does not focus on individual blame	Bargal et al. (2018)
6	STAMP is more effective than other methods in identifying hazards	Bas (2020), Kaya (2021), Silvis-Cividjian et al. (2020), and Yamaguchi and Thomas (2019)

The fifth advantage of STAMP is its focus on system factors rather than blaming individuals. One of the reviewed articles highlighted how STAMP guided users to focus their interventions on healthcare system redesign (Bargal et al., 2018). Similarly, Tonk and Boussif (2024) remarked that STAMP emphasises systemic factors when applied in railway. These findings suggest that STAMP supports a non-blaming approach, which can positively influence safety culture (Bond, 2008).

The sixth advantage identified in this review is the effectiveness of STAMP relative to other established methods. For example, the reviewed articles indicated its superiority over methods such as FRAM, FMEA, HFMEA, and FTA in identifying potential hazards in healthcare (Bas, 2020; Kaya, 2021; Silvis-Cividjian et al., 2020; Yamaguchi & Thomas, 2019). Likewise, a study in the coal mine industry highlighted how STAMP is superior to FRAM in identifying actionable recommendations (Qiao, Li, & Liu, 2019).

Reported Disadvantages

Overall, six papers highlighted several disadvantages, as shown in Table 3. The first disadvantage of STAMP is its limited use outside academic research in healthcare (Kaya, 2021; Patriarca et al., 2019). This may be linked to the second disadvantage, which is its complexity and perceived lack of user-friendliness (Bargal et al., 2018). However, another possibility is that practitioners simply prefer well-established methods (Patriarca et al., 2019), underscoring the need to better highlight STAMP's benefits.

Table 3: Summary of Reported Disadvantages of STAMP in Healthcare Applications

No	Reported Disadvantages	Author
1	STAMP is not widely utilized	Kaya (2021) and Patriarca et al. (2019)
2	STAMP is not user-friendly	Bargal et al. (2018)
3	STAMP does not provide a detailed description of hazard	Silvis-Cividjian et al. (2020)
4	There could be hazards that are not identified by STAMP	Pawlicki et al. (2016)
5	STAMP might include bias	Samost-Williams and Nanji (2020)

The third reported disadvantage is that STAMP does not provide a detailed description of hazards (Silvis-Cividjian et al., 2020), while the fourth is it may overlook some hazards (Pawlicki et al. (2016). Both of these limitations may hinder mitigation measures as information about hazards may not be specific enough or be incomplete. However, while these criticisms may be apparent when comparing tools for hazard analysis, the completeness of such analysis is inherently difficult to ascertain (Pawlicki et al. (2016).

The fifth reported disadvantage is the potential for bias to influence the outcome of analysis, particularly due to the less structured approach for generating causal scenarios in STAMP (Samost-Williams & Nanji, 2020). For example, availability bias may lead to more focus on frontline hazards, like medication errors, while overlooking risks from management, such as poor policies or resource issues. However, the authors noted that such biases can be managed through multidisciplinary input and the structured steps inherent in STAMP to identify unsafe control actions.

CONCLUSION

In conclusion, this study examined the medical departments using STAMP and summarized its advantages and disadvantages in healthcare, according to published studies. The review found that STAMP was most frequently reported in the radiology department (30%), followed by anaesthesiology (20%), and then in the pharmacy, cardiology, endocrinology, emergency, and NICU departments (each at 10%) STAMP's main advantages include its ability to identify potential hazards and unsafe actions, as well as generate recommendations to reduce risks. On the other hand, its limitations include underuse, difficulty of use, and potential bias. Overall, this review may help healthcare facilities consider STAMP as a tool to build safer systems.

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