



A comprehensive review of the Swiss cheese model in risk management

Tapiwa Shabani¹ · Steven Jerie¹ · Takunda Shabani¹

Received: 22 July 2023 / Revised: 4 September 2023 / Accepted: 19 September 2023 / Published online: 5 October 2023
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2023

Abstract

The SCM, developed by James Reason in the 1990s, is a widely recognized and influential model used to understand and manage complex systems and their associated risks. The aim of this review paper is to provide a comprehensive analysis of the Swiss Cheese Model (SCM) in the context of risk management. To conduct this review, an extensive literature search was performed using reputable academic databases, including PubMed, African Journals Online, Science Direct, Scopus, Springer, Google Scholar, and Sage Publications. The search included keywords such as SCM; Risk Management; Error Management and Risk Assessment. English journals published up to 2023 were considered for inclusion in this review. The review reveals that the SCM has been widely adopted across various industries, including healthcare, aviation, nuclear power, and transportation. Numerous studies have demonstrated its effectiveness in identifying potential risks, understanding their underlying causes, and implementing preventive measures. The model's core concept of multiple layers of defenses, represented by slices of cheese with holes (potential weaknesses), has proven valuable in visualizing how errors or failures can occur within complex systems. The review highlights the importance of organizational culture and leadership in successfully implementing the SCM. Results show that a positive safety culture, open communication channels, and strong leadership support are crucial for creating an environment where the SCM can be effectively utilized. This comprehensive review affirms the significance of the SCM as a valuable tool in risk management. However, recommendations shows that future research should focus on further refining the model's application in specific domains and exploring the importance of integrating it with other risk management frameworks.

Keywords Swiss cheese model · Risk management · Error management · Accident prevention · Risk assessment · Hazard identification · Risk mitigation

Introduction

Risk management is a critical aspect of various industries, including healthcare, aviation, nuclear power, and finance (Abu and Ugba [2022](#); Ahamad et al. [2022](#); Shabani et al. [2023a, b, c, d, e](#)). Risk management is a systematic process of identifying, assessing, and prioritizing potential risks and

implementing strategies to minimize or mitigate their impact on an organization or project (Chimwai and Munyanyi [2019](#); Filyppova et al. [2019](#); Fan [2020](#)). This suggests that risk management involves the identification of potential threats or uncertainties that could negatively affect the achievement of objectives of an organisation or industry, followed by the evaluation of their likelihood and potential consequences. The goal of risk management is to proactively identify and address risks in order to reduce the likelihood of negative events occurring and to minimize their impact if they do occur (Hao and Nie [2022](#); Hsu et al. [2022](#); Shabani et al. [2023a, b, c, d, e](#)). According to the US Bureau of Labour Statistics in ([2018](#)), the United States construction industry recorded 1,243 fatal accidents in 2005 however, there was a decline in the number of fatal accidents to 971 in 2017. This decrease can be attributed to the implementation of various accident management methods, notably risk management as

✉ Tapiwa Shabani
tapiwashaban@gmail.com
Steven Jerie
jeries@staff.msu.ac.zw
Takunda Shabani
shabstaku@gmail.com

¹ Department of Geography Environmental Sustainability and Resilience Building, Midlands State University, P. Bag 9055, Gweru, Zimbabwe

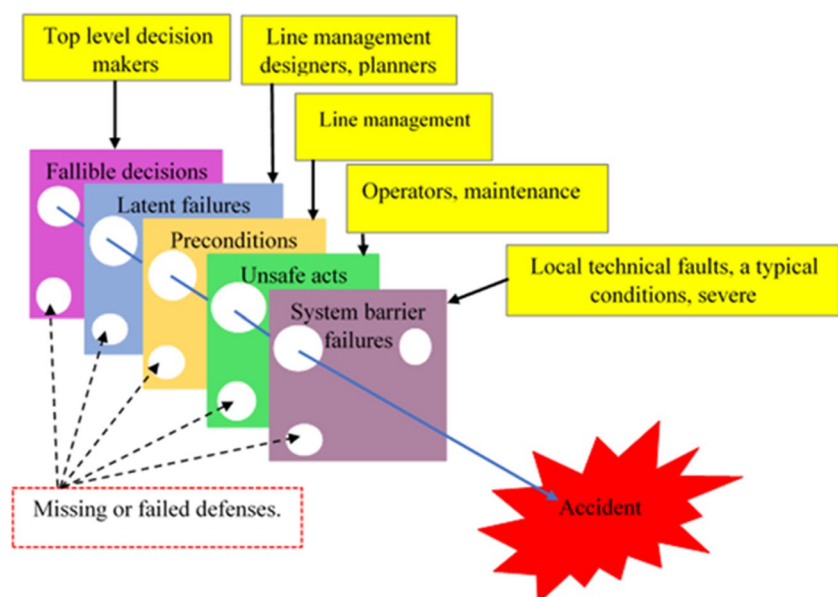
reported by the US Bureau of Labour Statistics in 2018. Risk management encompasses various activities and processes that are designed to manage risks effectively and these activities include risk identification, risk assessment, risk prioritization, risk treatment and risk monitoring and reviewing (Mabika 2018; Mavhura 2019; Jerie and Matunhira 2022). This postulates that if risk management practices are implemented effectively following its processes by organizations, they can proactively address uncertainties and enhance their ability to achieve their objectives.

Effective risk management provides several benefits to organizations (Musabayana et al. 2021; Mkungunugwa et al. 2022; Musungwa and Kowe 2022). This proposes that effective risk management helps organizations to anticipate and prepare for potential threats, reduces the likelihood of negative events occurring, minimizes financial losses, protects reputation and brand value, enhances decision-making processes, and improves overall organizational resilience. de Sant and de Hilal (2021); da Cunha et al. (2022) and González Barman (2023) opined that the Swiss Cheese Model (SCM) is a widely recognized and influential framework used in risk management. The Swiss Cheese Model was used for job hazard analysis in Oil Servicing Companies in Rivers State in Nigeria (Abu and Ugbah 2022). According to Leksir (2020), Lin et al. (2023) and Raharjo et al. (2023) the Swiss Cheese Model was first introduced by James Reason in the late 1990s as a conceptual framework for understanding accidents and errors in high-risk industries. In addition, Developed by James Reason, a prominent psychologist and researcher in the field of human error, the SCM provides a systematic approach to understanding and mitigating risks within complex systems (Fuad et al. 2019; Fu et al. 2020; Jong et al. 2020; Elsehrawy et al. 2021). This clearly

indicates that organisations can use the Swiss Cheese Model to analyse their systems, identify weak points, and implement appropriate measures to strengthen their defenses. The Swiss Cheese Model's simplicity and effectiveness in highlighting potential vulnerabilities have made it a valuable tool for risk management (Larouzee and Le Coze 2020; Karimi et al. 2021; Karanikas 2022). The Swiss Cheese Model was used as a framework for risk management in petroleum product distribution in Nigeria (Ambituuni 2016).

James Reason drew inspiration from earlier work on system safety and human factors engineering (Seshia et al. 2018; Sarin et al. 2020). Reason observed that accidents rarely occur due to a single cause but rather result from a combination of multiple failures within a system (Thonon et al. 2019; Toto and Limone 2019). The SCM metaphorically represents failures as "holes" in slices of cheese, with each slice representing a layer of defense against potential hazards (Warner et al. 2019; Wiegmann et al. 2022). The Swiss Cheese Model has key concepts as shown in Fig. 1 which include, active failures, latent conditions, defenses and barriers, as well as holes. Active failures refer to errors or violations committed by individuals directly involved in the system's operation (Wu et al. 2023; Young et al. 2023). Active failures can include mistakes made by pilots, surgeons, or operators. The industrial accidents that occurred in different parts of the world, namely the Chernobyl nuclear power plant catastrophe in 1986 in Ukraine, the Texaco Refinery explosion in 1994 in Wales, and the BP Deepwater Horizon Oil Spill disaster in 2010 in the Gulf of Mexico, were all major incidents that can be attributed to human error either directly or indirectly (Darabont et al. 2020; Shabani et al. 2023a, b, c, d, e). This submits that active failures are often the immediate triggers for accidents but

Fig. 1 Swiss Cheese Model.
Source: Fu et al. (2020)



are not necessarily the root causes of accidents. In addition, latent conditions are also among the key concepts of the SCM (Battisti 2018; Audinet et al. 2021). Latent conditions are underlying weaknesses or vulnerabilities within an organization or system that contribute to the occurrence or severity of active failures (Bialystok 2021; da Cunha et al. 2022; Chandra 2023). This clearly means latent conditions can include inadequate training, poor communication channels, insufficient resources, or flawed organizational culture.

According to da Sant (2022) defenses and barriers are considered to be part of the key components of the Swiss Cheese Model. Defenses and barriers represent measures put in place to prevent or mitigate risks within a system (Fu et al. 2020; Elsehrawy et al. 2021). This denotes that risk defenses and barriers include safety protocols, procedures, training programs, equipment design, and organizational policies to manage risks.

Defenses and barriers aim to reduce the likelihood of active failures and limit their potential consequences (Holtermann 2021; González Barman 2023). Further, the SCM is made up of holes in the Cheese. Holes on the SCM can occur due to human error, equipment malfunction, inadequate training, or other factors (Kamoun and Nicho 2018; Jong et al. 2020; Karanikas 2022). During the period from 2008 to 2018, an extensive investigation was conducted on a multitude of chemical accidents that occurred in South Korea and the findings revealed that human error accounted for a significant majority, specifically 76.1%, of all the chemical accidents that took place within this timeframe (Jung et al. 2020). This implies that holes in the cheese represent the weaknesses or vulnerabilities within each layer of defense. Karimi et al. (2021) and Line et al. (2023) opined that when multiple holes align across different layers of defense, they create a pathway for an accident or error to occur.

The Swiss Cheese Model has found widespread application in various industries concerned with risk management (Larouzee and Le Coze 2020; Maskari et al. 2023). The Swiss Cheese Model based accident analysis was used to identify the causes of an accident that took place in a driving school in Ghana (Toto and Limone 2019). Some notable applications of the Swiss Cheese Model include healthcare, aviation and nuclear power (Noh et al. 2020; Olson and Raz 2021; Mendes et al. 2022). This clearly indicates that the Swiss Cheese Model developed by English psychologist James Reason in the early 1990s, has become a widely recognised reference model for understanding, investigating, and preventing organisational accidents in various production systems such as transportation, energy and healthcare. In the realm of healthcare, Cohen et al. (2018) employed the Human Factors Analysis and Classification System (HFACS), which was created using the Swiss Cheese Model as a foundation, to categorize a total of 592 surgical near-misses that were documented through a hospital's incident

reporting system within a span of one year. While the Swiss Cheese Model has proven valuable in risk management, it is important to acknowledge its limitations. The SCM simplifies complex systems into discrete layers of defense, potentially oversimplifying the intricacies of real-world systems (Seshia et al. 2018; Puthillath et al. 2023; Raharjo et al. 2023). This means the Swiss Cheese Model may not fully capture all factors contributing to accidents or errors. Therefore, it is essential to recognize its limitations and explore possibilities for improvement to enhance its effectiveness in risk management. As a result, this review paper aims to provide a comprehensive overview of the Swiss Cheese Model in the context of risk management, examining the strengths and limitations of the Swiss cheese Model in risk management.

Findings of the review would become relevant to Sustainable Goal number 3 which focuses on Good Health and Well-Being. The study would increase the attainment of the Sustainable Development Goal number 9 which focuses on Industry, Innovation and Infrastructure. This indicates that the information becomes relevant to industries that deal with high risk operations such as nuclear and transportation. Through applying the findings of the review paper Sustainable Development Goal 11 which put more attention on Sustainable Cities and Communities will be achieved. This designates that the compiled information can be applied to urban planning and disaster management to identify potential risks and vulnerabilities within cities. By understanding the alignment of holes in different layers of defense, city planners can develop strategies to enhance resilience, mitigate risks associated with natural disasters, and create sustainable communities.

Methodology

The review paper was compiled by utilizing literature that had already been published. A thorough examination of existing literature was conducted with the aim of gathering relevant information pertaining to an all-encompassing analysis of the Swiss Cheese Model in the context of risk management. The literature on this subject is limited or lacking in quantity as a result other documents which involve aspects such as risk assessment and hazard identification were used during literature search. The retrieval of English literature published until 2022 was conducted with the aim of enhancing the validity and reliability of the data utilized in the compilation of the review. The measurement of the data's relevance was conducted by utilizing the abstract and keywords provided in the review paper. The data was searched using specific keywords which include Swiss Cheese Model, Risk Management, Error Management, Accident Prevention, Risk Assessment, Hazard Identification and Risk Mitigation.

A wide range of databases, including PubMed, African Journals Online, Science Direct, Scopus, Springer, Google Scholar, and Sage Publications, were extensively searched to identify significant articles. The collected data underwent screening and additional reduction to prioritize the essential information presented in current research, results, and methodologies of published papers. Various review papers and journals were utilized in gathering data for the study as they were crucial in providing information for different sections identified in the study.

Origins of the Swiss cheese model

The origins of the Swiss cheese model can be traced back to Reason's work on human error and accident causation (Thonon et al. 2019; da Cunha et al. 2022). In his book "Human Error" published in 1990, Reason introduced the concept of the "system approach" to understanding accidents (Evans et al. 2019; Wolf et al. 2021; Appicharla 2023). James Reason argued that accidents are not solely caused by individual errors but are often a result of systemic failures (Loh et al. 2020; Chandra 2023). This proposes that James Reason's earlier work focused on the concept of latent conditions, which are underlying organizational and environmental factors that contribute to accidents. James Reason identified various types of latent conditions, such as inadequate training, poor communication, and equipment failures (Wegman 2021; Degefu 2021; Green 2023). This clearly means latent conditions mentioned by James Reason can create the conditions for active failures (errors) to occur. Building upon this foundation, Reason further developed the Swiss cheese model to illustrate how multiple layers of defense can interact and fail in complex systems (Olson and Raz 2021; Wiegmann et al. 2022; Lewandowski et al. 2023). James Reason presented the model in his paper titled "The Human Contribution: Unsafe Acts, Accidents and Heroic Recoveries," published in 1997 (Yeow et al. 2020; Fu et al. 2020). In this paper, Reason described how each layer of defense in a system can have its own weaknesses or holes. These weaknesses can be due to factors such as design flaws, inadequate procedures, or human errors. James Reason states that when these weaknesses align across different layers, they create a clear pathway for an accident or error to penetrate through all the defenses (Larouzee and Le Coze 2020; Noh et al. 2020; Mendes et al. 2022). This designates that Reason emphasized that accidents are not caused by a single failure but are the result of a combination of failures aligning in an unfortunate sequence. Reason argued that preventing accidents requires a multi-layered approach, focusing on strengthening each layer of defense and reducing the likelihood of their alignment (Jong et al. 2020; Karimi et al. 2021; Maskari et al. 2023). Reason's argument causes the Swiss cheese model to gain significant popularity and recognition

within the field of risk management and safety engineering. This postulates that the SCM provides a visual representation that resonated with safety practitioners and helped them to understand the complex nature of accidents and errors in systems.

Components of the Swiss cheese model

The Swiss Cheese Model consists of several key components that interact with each other to create a system's overall safety or vulnerability (Wen et al. 2022; Singo et al. 2022a, b, c; Puthillath et al. 2023). This indicates that the Swiss Cheese Model suggests that accidents happen when multiple failures align, allowing hazards to penetrate through the holes in the defenses. The components of the Swiss Cheese Model include active failures (Larouzee and Le Coze 2020; Young et al. 2023). Active failures refer to the immediate actions or decisions made by individuals within a system that can directly lead to an accident or error (Jing et al. 2020; Karimi et al. 2021; Raharjo et al. 2023). This denotes that the SCM indicates that active failures are often caused by human error, such as mistakes, lapses in attention, or violations of established procedures. Active failures are considered the most visible and immediate cause of accidents (Song et al. 2020; Norazahar 2020; Saeidi Keshavarz et al. 2020). The Swiss Cheese Model also includes latent conditions as part of its components (da Cunha et al. 2022). Latent conditions are underlying weaknesses or flaws within an organization or system that may not be immediately apparent but can contribute to accidents over time (Fan 2020; Wen et al. 2022). Nkosi et al. (2020) and Hald et al. (2021) latent conditions include inadequate training, poor communication, equipment malfunctions, design flaws, staffing issues, or organizational culture problems. This implies that latent conditions are often present long before an accident occurs and can create an environment where active failures are more likely to happen. Unlike active failures, latent conditions are not immediately apparent and may exist for long periods before they manifest as active failures. The Swiss Cheese Model emphasizes the importance of understanding and addressing both active failures and latent conditions to improve safety and prevent accidents (da Cunha et al. 2022; Wiegmann et al. 2022). By understanding the relationship between active failures and latent conditions, organizations implement strategies to improve safety and reduce the likelihood of accidents. This involve measures such as enhancing training programs, improving communication channels, redesigning processes or equipment, fostering a culture of safety, and implementing effective error reporting and analysis systems.

Preconditions are considered to be part of the Swiss Cheese Model (Karimi et al. 2021; Wiegmann et al. 2022). According to Raharjo et al. (2023) preconditions are factors

that increase the likelihood of active failures occurring. Precondition factors include time pressure, fatigue, stress, inadequate resources, and lack of supervision or conflicting goals (Ebrahimi et al. 2021; Olson and Raz 2021). This advocates that preconditions set the stage for active failures by creating an environment where individuals are more prone to making mistakes or taking shortcuts which enhance accidents. Additionally, the components of the Swiss Cheese Model encompass defenses (Sarin et al. 2020; Larouzee and Le Coze 2020). Defenses represent the barriers and safeguards put in place to prevent accidents from occurring or mitigate their consequences (Elsehrawy et al. 2021; Sehgal 2023). Defenses applied by the SCM include safety protocols, procedures, training programs, equipment maintenance, safety inspections, alarms, warning systems and safety audits (Fu et al. 2020; Sultan et al. 2019). This clearly indicates that defenses act as layers of protection against active failures and latent conditions. The Swiss Cheese Model also presents holes as part of its components (Olson and Raz 2021; Yuan et al. 2022). Haghani et al. (2023) designated that holes in the Swiss Cheese Model represent the weaknesses or vulnerabilities within each layer of defense. Holes on the SCM occur due to human error, equipment failures, inadequate training, poor communication, poor management commitment and poor safety feedback as well as improper reporting of near-miss incidents (Leksir 2020; González Barman 2023). This clearly indicates that when holes in different layers align, they create a pathway for an accident or error to occur.

Application of the Swiss cheese model in risk management

The application of the Swiss Cheese Model in risk management involves several steps (Jong et al. 2020; Karimi et al. 2021; Wiegmann et al. 2022). The first step of applying the SCM is to identify potential hazards or risks within a system or processes (Audinet et al. 2021; Hao and Nie 2022). This suggests that application of the SCM enhances hazard identification within an organization. Hazard identification is done through various methods such as risk assessments, incident investigations and safety audits as well as data analysis (Mavhura 2019; Jerie and Matunhira 2022; Shabani et al. 2023a, b, c, d, e). Once the hazards are identified, the next step is to analyse the existing defenses or control measures in place. This proposes that application of the Swiss Cheese Model in risk management involves assessing the effectiveness of each layer of defense and identifying any weaknesses or gaps that could allow hazards to pass through. In the third stage the Swiss Cheese Model is used to map out the different layers of defense and their potential weaknesses (Chandra 2023; Xie and Peng 2023). This clearly indicates that the application of the Swiss Cheese Model

in risk management helps to visualize how hazards could potentially pass through the system and cause accidents.

In addition, in stage 4 of applying the Swiss Cheese Model in risk management methods to manage identified risks are developed. Based on the analysis and mapping, risk management strategies can be developed to mitigate the identified risks (González Barman 2023; Yalcin et al. 2023). This recommends that application of the SCM in risk management involves strengthening existing defenses, implementation of additional controls, or redesigning processes to minimize the likelihood of hazards passing through all layers. Moreover, in stage 5 monitoring and continuous improvement of the SCM in risk management is performed. Risk management is an ongoing process, and it is important to continuously monitor and review the effectiveness of the implemented controls (Mkungunugwa et al. 2022; Chigara and Moyo 2020; Shabani et al. 2023a, b, c, d, e). This entails that application of the Swiss Cheese Model in risk management should involve regular audits, inspections and feedback mechanisms to be in place to identify any new hazards or weaknesses that may arise. When incidents or accidents occur despite the implemented risk controls, it is important to learn from them and make improvements accordingly (Abu and Ugba 2022). Learning from accidents involve conducting thorough investigations to understand the root causes of the incident, identifying any gaps in the defense layers, and implementing corrective actions to prevent similar incidents in the future (Ahamad et al. 2022; Appicharla 2022). Steps involved when using the Swiss Cheese Model in Risk Management are summarised in Table 1.

Critiques and debates of the Swiss cheese model

The model represents each layer of defenses as a slice of cheese with holes, implying that failures occur randomly and independently (Larouzee and Le Coze 2020; Noh et al. 2020). However, in reality, failures often interact with each other in complex ways, making it difficult to accurately represent them as discrete layers (Lin et al. 2023; Wu et al. 2023). This clearly shows that oversimplification can lead to a false sense of security and may hinder organisations from fully understanding the intricacies of their systems. Although the Swiss Cheese Model has been widely embraced and applied in various industries, it is associated with critiques and debates (Stosic et al. 2022; Qiao et al. 2022). The critique of the Swiss Cheese Model is related to the assumption that errors are solely caused by individual actions or failures (Yeow et al. 2020; Leksir 2020). This implies that the Swiss Cheese Model primarily focuses human error as the main contributor to accidents, neglecting other factors such as organizational culture, system design flaws or external pressures. However, this narrow focus on individual behaviour can lead to a blame oriented approach

Table 1 Steps involved in applying the Swiss cheese model in risk management

Steps Involved In Applying the Swiss Cheese Model In Risk Management	References
1. Identify Hazards (The first step is to identify potential hazards or risks within the system or organization)	Jong et al. 2020; Karimi et al. 2021; Wiegmann et al. 2022; Chandra 2023; Xie and Peng 2023
2. Analyse Defenses (Once the hazards are identified, the next step is to analyse the existing defenses or barriers that are in place to prevent these hazards from causing harm)	
3. Assess Vulnerabilities (In this step, the vulnerabilities or weaknesses in each defense layer are assessed)	
4. Identify Potential Errors (Once vulnerabilities are identified, it is important to understand the potential errors that could occur within each defense layer)	
5. Implement Risk Controls (Based on the vulnerabilities and potential errors identified, appropriate risk controls or interventions should be implemented)	
6. Monitor and Review (Risk management is an ongoing process, and it is crucial to continuously monitor and review the effectiveness of the implemented risk controls)	
By following these steps, organizations can effectively apply the Swiss cheese model in risk management to enhance safety and prevent accidents or incidents	

rather than a systematic approach to safety improvement. Critiques of the Swiss Cheese Model argue that by solely attributing accidents to human error, organizations may miss opportunities to address underlying systemic issues (Lu 2021; Torres et al. 2022).

Furthermore, some critics argue that the Swiss Cheese Model does not adequately address the role of organizational factors in shaping safety outcomes (Holtermann 2021; Abu and Ugba 2022). This suggests that the Swiss Cheese Model acknowledges how the organization influences individual behaviour, it does not provide a comprehensive framework for analysing and addressing organizational factors. Organizational culture, leadership practices, communication patterns and resource allocation are all critical elements that can significantly impact safety performance but are not explicitly incorporated into the Swiss Cheese Model (de Sant and de Hilal 2021; Ahamad et al. 2022; Haghani et al. 2023). In addition, debates surrounding the Swiss Cheese Model also revolve around its practical application. Some argue that the model’s simplicity makes it accessible and easy to understand, facilitating its adoption in various industries (Jing et al. 2020; Goddu 2021; Chandra 2023). This connotes that the model lacks specificity and guidance on how to effectively implement risk management strategies. Critics argue that organizations may struggle to translate the conceptual framework into actionable practices, leading to limited effectiveness in preventing accidents (Seshia et al. 2018; Smith and Plunkett 2019; Bialystok 2021). Despite these critiques and debates, it is important to note that the Swiss Cheese Model has made significant contributions to the field of risk management and safety. The Swiss Cheese

Model has been widely used in industries such as healthcare, aviation and nuclear power, where safety is of paramount importance (Kamoun and Nicho 2018; Karimi et al. 2021; Wiegmann et al. 2022). This entails that the SCM has helped to raise awareness about the importance of multiple layers of defenses and the need for a systematic approach to safety improvement.

Strengths and weaknesses of the Swiss cheese model

The Swiss Cheese Model has been widely adopted and praised for its effectiveness in understanding and managing risks; however, it also has its own set of strengths and weaknesses (Battisti 2018; Song et al. 2020; Karanikas 2022). One of the key strengths of the Swiss Cheese Model is its ability to provide a clear and intuitive visual representation of complex systems and their vulnerabilities (Adriaensen et al. 2019; Larouzee and Le Coze 2020). The Swiss Cheese Model was used as a method to improve occupational safety and health in complex systems of industry 4.0 (Adriaensen et al. 2019). Additionally, Chen et al. (2023) opined that the Swiss Cheese Model is effecting in addressing accidents in complex systems. This connotes that the model uses layers of cheese slices to represent different defenses barriers, with holes representing potential weaknesses or failures in those barriers. Visual representation of the Swiss Cheese Model helps stakeholders to easily understand how multiple failures can align to create a pathway for accidents or adverse events (Mwamba et al. 2022; Haghani et al. 2023). This entails that SCM emphasizes that accidents are rarely caused by a single

factor or individual error but are often the result of multiple failures aligning in an unfortunate sequence. As a result, by considering the interdependencies between different layers of defense, organizations can gain a holistic understanding of their vulnerabilities and develop more robust risk management strategies. The Swiss Cheese Model promotes a holistic perspective on risk management by considering both active and latent failures (Appicharla 2022; Mendes et al. 2022; Raharjo et al. 2023). The Swiss Cheese Model was used as a best practice for risk management approach in pharmacy management (De Silva 2018). In United States the Swiss Cheese Model was used to assess safety attitudes of employees at Airports (Oztekin 2018). This means the Swiss cheese model encourages organizations to adopt a proactive rather than reactive approach to risk management. Instead of solely focusing on individual errors or failures, the Swiss Cheese Model emphasizes the importance of identifying systemic weaknesses and implementing preventive measures (Wen et al. 2022; Puthillath et al. 2023). Hence, this shift lead to a culture of continuous improvement and learning within organizations.

In addition, the visual representation of the Swiss Cheese Model is helpful in simplifying complex systems however, it can also oversimplify reality (Noh et al. 2020; da Cunha et al. 2022). However, in real-world scenarios, there may be numerous interdependencies and interactions between different layers of defense, making it challenging to accurately represent them with a simple visual model (Thonon et al. 2019; Toto and Limone 2019). This clearly means this oversimplification can lead to a false sense of security or an underestimation of the complexity of risk management. As a result, organizations need to be cautious not to rely solely on the Swiss Cheese Model and should consider other risk assessment tools and methodologies to ensure a comprehensive understanding of their risks. The Swiss Cheese Model acknowledges the role of human error in accidents; it does not provide a comprehensive understanding of human factors and their influence on risk management (Puthillath et al. 2023; Maskari et al. 2023). According to the investigation done in United States Food and Drug Administration in 2019, the primary cause of medical incidents, resulting in 60% of all related deaths or injuries, is attributed to human error (Song et al. 2020). This denotes that the Swiss Cheese Model limits its focus on human factors which causes risks within the workplace. Human error is often influenced by various factors such as fatigue, stress, workload and organizational culture (Wu et al. 2022; Mohammadfam et al. 2022; Shabani et al. 2023a, b, c, d, e). By not explicitly addressing these factors, the model may overlook important aspects of risk management related to human performance. Hence, decision-making within organizations should consider additional frameworks or theories that focus on human factors, such as the Human Factors Analysis and Classification

System (HFACS), to complement the Swiss cheese model. The Swiss Cheese Model is often criticized for its static nature, as it assumes that the layers of defense remain constant overtime (Jong et al. 2020; Wiegmann et al. 2022; Buist and Arnold 2022). In reality, organizations and systems are dynamic, constantly evolving and changing (Battisti 2018; Audinet et al. 2021). This indicates that new risks may emerge and existing defenses may become outdated or ineffective. Therefore, it is important for organisations to regularly assess and update the layers of defense to increase their effectiveness (Degefu 2021; da Cunha et al. 2022).

Practical implications of the Swiss cheese model in risk management

Risk management is a crucial aspect of any organization's operations, as it involves identifying, assessing and mitigating potential risks that could impact the achievement of objectives (Jerie and Matunhira 2022; Mkungunugwa et al. 2022; Shabanni et al. 2023). This clearly indicates that practical implications of effective risk management are numerous and can significantly contribute to the success and sustainability of an organization. The primary practical implications of risk management is its ability to improve decision making processes within an organization (Van Thuyet et al. 2019; Shahid et al. 2019; Alzoubi 2022). This implies that risk management using the Swiss Cheese Model is vital in enhancing decision making. By identifying and assessing potential risks, organizations can make informed decisions that take into account the potential consequences and the likelihood of those risks occurring. Risk management allows for more accurate forecasting and planning, enabling organisations to allocate resources effectively and make strategic choices with their risk (Munir et al. 2020; van der Schaar et al. 2021).

In addition, risk management using the Swiss Cheese Model protects the reputation of the organization (Karimi et al. 2021; da Cunha et al. 2022). Chimwai and Munyanyi (2019) and Nyanga (2020) opined that reputation is a valuable asset that can be easily damaged by unforeseen events or crises. This postulates that by implementing robust risk management practices, industries can identify and mitigate risks that could affect their reputation. Risk management includes proactive measures such as communication, monitoring and stakeholder engagement strategies (Singo et al. 2022a, b, c; Musungwa and Kowe 2022; Jerie and Matunhira 2022). Organizations maintain trust and credibility with stakeholders by effectively managing risks, which is essential for long term success. Effective risk management using the Swiss Cheese Model led to cost reduction for organizations (Norazahar 2020; Fan 2020; Lin et al. 2023). This implies that the practice of identifying and mitigating potential risks in organizations using the Swiss Cheese

Model avoids or minimizes financial loss. Implementation of proper safety protocols reduce the likelihood of workplace accidents, resulting in lower insurance premiums and legal costs (Chigara and Moyo 2022; Mapuvire et al. 2022; Shabani et al. 2023a, b, c, d, e). This clearly indicates risk management practices using the Swiss Cheese Model identify potential disruptions and enable organizations to develop contingency plans or alternative sourcing strategies, reducing the financial impact of supply chain interruptions.

Risk management using the Swiss Cheese Model increases compliance of organizations to safety regulations (Fuad et al. 2019; Zhao et al. 2021; Ngo 2021). According to a study carried in Zimbabwe, the Swiss Cheese Model could be applicable to Artisanal and Small Scale Gold Miners (ASGM), which is associated with hazardous working conditions (Singo et al. 2022a, b, c). This entails that risk management plays a crucial role in ensuring compliance with regulations and legal requirements. Organizations operate within a complex web of laws and regulations that govern their activities (Mabika 2018; Gwezuva and Jerie 2018; Nyanga 2022). This suggests that failure to comply with safety regulations can result in legal penalties, reputational damage and even business closure. By implementing effective risk management practices, organizations identify and address potential compliance risks, ensuring that they operate within the boundaries of the law. In addition, risk management using the Swiss Cheese Model improves stakeholder confidence in an organization (Larouzee and Le Coze 2020; Young et al. 2023; Puthillath et al. 2023). This proposes that stakeholders, including investors, customers, employees and regulators want assurance that an organization is well-managed and capable of navigating potential risks. The use of Swiss Cheese Model as a risk management framework in organizations instil confidence in stakeholders that their interests are being protected (Sheehan et al. 2021; Kim et al. 2023). This intends that risk management using the Swiss Cheese Model increases investment, customer loyalty, employee satisfaction and regulatory support.

The use of the Swiss Cheese Model increases business continuity in the face of unexpected incidents or events (Azadegan et al. 2019; Warner et al. 2019; Kirwan et al. 2021). This clearly indicates that identifying and assessing potential risks using the Swiss Cheese Model enhances the ability of the organizations to develop contingency plans and strategies to minimize disruptions to operations. Measures developed to increase business continuity after identification of risk using the SCM include disaster recovery plans, backup systems, business interruption insurance and continuous safety audits (Zhang et al. 2019; Taherdoost 2021; Wu et al. 2023). This signifies that effective risk management using the Swiss Cheese Model allows organizations to respond swiftly and effectively to risks, minimizing downtime and ensuring the continuity of critical business

functions. Moreover, the use of the SCM in risk management causes the industries to be competitive (Saeidi Keshavarz et al. 2020; Abu and Ugba 2022; Ahmad Azwan 2022). This connotes that industries that apply frameworks such as the Swiss Cheese Model in managing risks gain a competitive advantage over other industries. By proactively identifying and mitigating risks, organizations can position themselves as more reliable and trustworthy partners or suppliers (Jerie and Matunhira 2022; Shabani et al. 2023a, b, c, d, e). This proposes that effective risk management leads to increased market share, customer loyalty and differentiation from competitors who may be less prepared for potential risks. If the Swiss Cheese Model is applied in risk management it facilitates innovation within organizations (Karimi et al. 2021; da Cunha et al. 2022; Wiegmann et al. 2022). This offers that understanding and managing risks using the Swiss cheese Model is associated with new ideas or ventures and creation of an environment that encourages experimentation and creativity. After Fire Quantitative Risk Assessment of tanks used to store petroleum in the Tehran Refinery in Iran was performed using the Loss Causation and Swiss Cheese Model novel ideas were used to design new model for risk assessment (Saeidi Keshavarz et al. 2020). Effective risk management practices allow organizations to take calculated risks while minimizing potential negative consequences (Filyppova et al. 2019; Santos and de Oliveira 2019; Siegrist et al. 2021). This means that use of SCM in risk management fosters a culture of innovation where employees feel empowered to propose new ideas without fear of excessive risk.

Challenges organisations face in applying the Swiss cheese model

While the Swiss Cheese Model offers a valuable approach to risk management, organizations often face several challenges when implementing it (Battisti 2018; Audinet et al. 2021; Bialystok 2021). Implementing the Swiss Cheese Model requires a strong commitment to safety and risk management from all levels of an organization (Elsehrawy et al. 2021; da Cunha et al. 2022). However, some organizations may have a culture that prioritizes productivity over safety or lacks a proactive approach to risk management. Fuad et al. (2019) and Holtermann (2021) indicated that it is challenging to shift the traditional strategies used within the organisation and create a culture that embraces the principles of the Swiss Cheese Model. Additionally, the Swiss Cheese Model emphasizes the importance of integrating various risk management activities across different functions and departments within an organization (Larouzee and Le Coze 2020; Jong et al. 2020; Karimi et al. 2021). Nevertheless, organizations may struggle with old approaches of risk management, where each department or function operates independently

without considering the broader organizational context. This lack of integration result in fragmented defense layers and reduce the overall effectiveness of risk management efforts.

Implementing the Swiss Cheese Model often involves investing resources in various areas such as training programs, technology upgrades, process improvements, and regular risk assessments (Leksir 2020; Lewandowski et al. 2023). According to Lin et al. (2023) organizations face resource constraints, including financial limitations or limited availability of skilled personnel and these constraints hinder the implementation process and make it difficult to establish robust layers of defense. Effective communication is crucial for successful implementation of the Swiss Cheese Model (Loh et al. 2020; Maskari et al. 2023). This implies that organizations need to ensure that all stakeholders understand their roles and responsibilities in managing risks and actively participate in the process. Mkungunugwa et al. (2022) and Mendes et al. (2022) opined that communication breakdowns occur due to hierarchical structures, lack of transparency, or inadequate information sharing mechanisms. Hence, poor communication issues lead to gaps in the defense layers and compromise the effectiveness of the Swiss Cheese Model in risk management. Implementing the Swiss Cheese Model often requires changes in existing processes, procedures, and behaviours (Noh et al. 2020; Norazahar 2020; Olson and Raz 2021). Resistance to change is a common challenge faced by organizations during any implementation effort, including risk management initiatives (Nunu et al. 2018; Shabani et al. 2021). This suggests that employees resist new practices due to fear of the unknown, perceived loss of control, or skepticism about the benefits of the model.

Integration of the SCM with other risk management models

Integrating the Swiss Cheese Model with other risk management models enhances its capabilities and provides a more comprehensive approach to risk mitigation (Song et al. 2020; Yuan et al. 2023). This advocates that combining the strengths of different models, can help organizations to gain a deeper understanding of their risks, analyse potential hazards and consequences, identify interventions at different stages, and prioritize resources effectively. Integrating the Swiss Cheese Model with other risk management models such as hierarchy of controls enhance the effectiveness of risk management practices (Karimi et al. 2021; Logrosa et al. 2022). The hierarchy of controls is a risk management framework that prioritizes different types of controls based on their effectiveness in reducing or eliminating risks (Jerie and Musasa 2022; Shabani et al. 2023a, b, c, d, e). The hierarchy of control consists of five levels: elimination, substitution, engineering controls, administrative controls and

personal protective equipment/cloth (PPE/C) (Singo et al. 2022a, b, c; Chigara and Moyo 2022). This proposes that integrating the Swiss Cheese Model with the hierarchy of controls can help organisations to identify which layers of defense align with each level of control. Integration of the Swiss Cheese Model and the hierarchy of controls is vital since it determines the most effective control measures for mitigating risks at different layers of defense (Saeidi Kes-havarz et al. 2020; Hao and Nie 2022). This entails that integration of the Swiss Cheese Model enables organisations to focus on implementing controls that have a higher likelihood of preventing or minimizing risks.

The Swiss Cheese Model is commonly integrated with the Bowtie Model, which is another popular risk management tool used to analyze and visualize potential hazards and their consequences (Song et al. 2020; Zhao et al. 2021). The Bowtie Model focuses on identifying the causes and consequences of an incident, as well as the preventive barriers that can be implemented (Aust and Pons 2020; Bijay et al. 2020). This postulates that integrating the Swiss Cheese Model with the Bowtie Model enhances the ability of the organizations to identify how failures in each layer of defense can lead to specific hazards and consequences. As a result, integration allows for a more detailed analysis of potential risks and helps in designing targeted preventive measures. Furthermore, the Swiss Cheese Model can also be integrated with the Risk Matrix, which is a tool used to assess and prioritize risks based on their likelihood and severity (Ibrahim and Patruni 2019; Kadena and Keszthelyi 2022). Moreover, by incorporating the Swiss Cheese Model into the Risk Matrix, organizations can evaluate the effectiveness of their existing defenses and identify areas where additional controls or preventive measures are needed (Hsu et al. 2022; Liou et al. 2022). This clearly shows that integration of the Swiss Cheese Model and the Risk Matrix helps in prioritizing resources and efforts towards addressing the most critical vulnerabilities.

The integration of the Swiss Cheese Model with Fault Tree Analysis (FTA) and Failure Mode Effect Analysis (FMEA) can provide a comprehensive approach to understanding and managing complex systems and their potential failures (Song et al. 2020; Cheshmberah et al. 2020). This infers that these three methodologies (Swiss Cheese Model, Fault Tree Analysis and Failure Mode Effect Analysis) can be widely used in various industries, including aviation, healthcare, nuclear power, and manufacturing, to identify and mitigate risks. For example, the effectiveness of the medical therapeutic respirators from Beijing Haidian Hospital was assessed by employing the enhanced Failure Mode Effect Analysis method and the Swiss Cheese Model to evaluate the evaluate the potential risks associated with their clinical use (Song et al. 2020). Fault Tree Analysis (FTA) is a systematic approach used to analyse the causes

of system failures (Ding et al. 2021; Xiao et al. 2023). In addition, FTA starts with identifying the top-level undesired event or failure and then breaks it down into contributing events or conditions using logic gates such as AND, OR, and NOT (Pan et al. 2022; Yazdi et al. 2023). This recommends that the fault tree diagram provides a graphical representation of the logical relationships between events and helps identify the root causes of failures. For example, in aviation, the integration of these methodologies can help identify the causes of accidents or incidents by analysing the contributing events using FTA (Ma et al. 2022; Xiao et al. 2023). This shows that the FTA is used to assess the potential failure modes and their effects on flight safety and the Swiss Cheese Model provides a visual representation of the multiple layers of defenses, including human factors, organizational factors, and technical controls and how they interact to prevent accidents. Moreover, the advanced FTA methodologies have found extensive application in various fields such as Computer Science, Mathematics, Energy, Environmental Science, and Decision Sciences and these disciplines have utilized FTA approaches for risk management purposes, with respective percentages of 17%, 8.5%, 6.7%, 5.1%, and 3.9% (Yazdi et al. 2023). In healthcare, integrating the Swiss Cheese Model, Fault Tree Analysis and Failure Mode Effect Analysis help to identify potential risks in patient safety (Qiao et al. 2020; Wiegmann et al. 2022). This advocates that FTA can be used to analyse the causes of adverse events or medical errors, while FMEA can assess the potential failure modes in medical processes or procedures and the Swiss Cheese Model can provide insights into the vulnerabilities in the healthcare system and guide the implementation of preventive measures. As a result, integrating the Swiss Cheese Model into risk assessment and mitigation processes, help organizations to gain a deeper understanding of potential risks and develop more effective strategies to prevent or mitigate them. Integrating the Swiss Cheese Model into risk assessment and mitigation processes significantly enhance an organization's ability to identify, understand, and manage risks in complex systems (Puthillath et al. 2023; Maskari et al. 2023). Through visualizing vulnerabilities, understanding systemic risks, improving risk communication, enhancing risk assessment, developing layered defenses, and promoting continuous improvement, organizations build a more resilient and proactive approach to risk management (Shabani et al. 2023a, b, c, d, e; Shabani et al. 2023a, b, c, d, e; Shabani et al. 2023a, b, c, d, e).

Future directions and enhancement of the Swiss cheese model

According to Haghani et al. (2023) the Swiss Cheese Model has been widely adopted and applied in various industries, but there are several future directions and potential

enhancements that can further improve its effectiveness in risk management. The Swiss Cheese Model can be enhanced by incorporating human factors more explicitly (Jing et al. 2020; Young et al. 2023; Puthillath et al. 2023). This implies that human error is often a significant contributor to accidents and adverse events, and considering human factors within the Swiss Cheese Model can provide a more comprehensive understanding of the risk. Integration of human factors involve analysing human performance, involvement of workers in decision making, check the workload of workers and other cognitive factors that influence the effectiveness of each layer of defense (Jerie and Jenya 2017; Nunu et al. 2018; Musabayana et al. 2021).

In addition, the traditional Swiss Cheese Model assumes static layers of defense that remain constant overtime (Olson and Raz 2021; Raharjo et al. 2023). However, in complex systems, the effectiveness of these layers can change due to various factors such as organisational changes, technological advancements or external influences. This denotes that enhancing the Swiss Cheese Model to account for dynamic and adaptive layers of defense would allow for a more accurate representation of risk management in evolving environments. The Swiss Cheese Model provides a qualitative understanding of risk (Sarin et al. 2020; Larouze and Le Coze 2020), as a result incorporating quantitative analysis and metrics can enhance its practical application. This means by assigning probabilities and consequences to each layer of defense, organisations can prioritize their efforts and allocate resources more effectively. Incorporating probabilities to the Swiss Cheese Model enable a more data driven approach to risk management and facilitate comparisons between different risks or mitigation strategies (Fu et al. 2020; Elsehrawy et al. 2021). The Swiss Cheese Model should incorporate feedback loops (González Barman 2023). In addition, feedback loops play a crucial role in risk management as they allow for continuous learning and improvement (Leksir 2020; Jong et al. 2020). This entails that by integrating feedback loops within the Swiss Cheese Model, organisations can capture and analyse data from near-missing incidents and accidents to identify patterns and trends. Information collected through feedback loops is used to refine the layers of defense and address potential weaknesses proactively to enhance risk management (Audinet et al. 2021; Hao and Nie 2022).

Enhancement of the Swiss Cheese Model can be done through integration of the model with advanced technologies (Noh et al. 2020; Chandra 2023). According to Lin et al. (2023) and Wu et al. (2023) the advancement of technologies such as geographic information systems and data analytics presents an opportunity to enhance the Swiss Cheese Model. In addition, technologies automate the analysis of vast amounts of data, identify patterns and predict potential failures or risks (Torres et al. 2022; Stosic et al. 2022). This

implies that integrating technologies in the Swiss Cheese Model help organisations to gain real time insights and make more informed decisions regarding risk management. While the Swiss Cheese Model has been widely applied in industries such as aviation, healthcare and nuclear power, there is potential for its application in new domains (Seshia et al. 2018; Holtermann 2021; de Sant and de Hilal 2021). This recommends that the Swiss Cheese Model could be adopted for cybersecurity risk management or supply chain risk management. However, expanding the application of the model to new domains would require tailoring it to specific contexts and identifying domain-specific layers of defense.

Conclusion and recommendations

This review paper titled "A Comprehensive Review of the Swiss Cheese Model in Risk Management" provides a thorough examination of the Swiss Cheese Model (SCM) and its application in risk management. The SCM is a widely recognized and influential model that helps organizations understand and manage complex systems and processes to prevent accidents and mitigate risks. The paper begins by introducing the concept of the SCM and its origins in the field of aviation safety. It explains how the model visualizes a system as a series of barriers or slices of cheese, each with its own potential for failure or error. These barriers can be organizational, procedural, technical, or human in nature. The model suggests that accidents occur when multiple failures align, creating a pathway for an adverse event to occur.

The review paper then delves into the various components of the SCM, discussing each layer of defense and its role in preventing accidents. It explores how these layers interact with each other and how their effectiveness can be influenced by factors such as organizational culture, communication, and training. The paper also examines the limitations of the SCM, acknowledging that it is not a solution but rather a tool for understanding and managing risks.

Furthermore, the review paper discusses real-world applications of the SCM across different industries such as healthcare, nuclear power, transportation, and manufacturing. It highlights case studies where the SCM has been successfully implemented to identify vulnerabilities in systems and improve safety measures. Additionally, it addresses criticisms and debates surrounding the model, including concerns about oversimplification and its reliance on hindsight bias. Overall, this comprehensive review paper provides a deep analysis of the Swiss Cheese Model in risk management. It offers insights into its strengths, weaknesses, and practical applications across various industries. By understanding the complexities of systems and how failures can occur at different levels, organizations can use the SCM as a valuable tool to enhance their risk management strategies.

As a result, organizations should invest in training programs and workshops to enhance employees' understanding of the Swiss Cheese Model. This will enable them to identify potential risks more effectively and implement appropriate defenses. Organizations should recognize the importance of human factors in risk management and incorporate them into their application of the Swiss Cheese Model. This includes considering human error probabilities, cognitive biases and organisational culture when analysing risks. Organizations should adopt a continuous improvement mind-set when using the Swiss Cheese Model. Regularly reviewing and updating defenses, identifying new vulnerabilities, and learning from past incidents will help enhance risk management practices.

Acknowledgements All sources were acknowledged.

Author's contributions Tapiwa Shabani and Takunda Shabani were responsible for coming up with the idea, doing literature search and data analysis under supervision of Steven Jerie. Tapiwa Shabani and Takunda Shabani developed the final draft and proofread the document and further adjustments were done by Steven Jerie.

Funding The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

Data availability The data generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

Ethics approval Approval was granted by Midlands State University to carry out the research as well as to publish under its name. All sources were properly cited to avoid plagiarism.

Consent to participate All authors participated and agreed to participate up to the final revision of the manuscript.

Consent for publication Authors agreed to let the paper be published when considered for publication.

Conflicts of interest This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

References

- Abu O, Ugba S (2022) An assessment of job hazard analysis and safety performance in indigenous oil servicing companies in Rivers State, Nigeria. *Int J Health Soc Inquiry* 8(1). <https://journals.aphriapub.com/index.php/IJHSI/article/view/1590>
- Adriaenssens A, Decré W, Pintelon L (2019) Can complexity-thinking methods contribute to improving occupational safety in industry 4.0? A review of safety analysis methods and their concepts. *Safety* 5(4):65 (<https://www.mdpi.com/2313-576X/5/4/65>)
- Ahamad, M. A., Arifin, K., Abas, A., Mahfudz, M., Cyio, M. B., Khairil, M. and Samad, M. A. (2022). Systematic literature

- review on variables impacting organization's zero accident vision in occupational safety and health perspectives. *Sustainability*, 14(13), 7523. <https://www.mdpi.com/2071-1050/14/13/7523>.
- Ahmad Azwan A (2022) Evaluation of safety health and environment at selected area: Construction site/Ahmad Azwan Anuar (Doctoral dissertation, Universiti Malaya). <http://studentsrepo.um.edu.my/id/eprint/14323>
- Alzoubi HM (2022) BIM as a tool to optimize and manage project risk management. *Int J Mech Eng* 7(1). https://kalaharijournals.com/resources/IJME_Vol7.1_658
- Appicharla S (2023) The Boeing 737 Max 8 Crashes: System-based Approach to Safety—A Different Perspective. *Safety-Critical Systems eJournal*, 2(1). <https://scsc.uk/journal/index.php/scsj/article/view/18>
- Appicharla SK (2022) From Nobel Prizes to Safety Risk Management: How to Identify Latent Failure Conditions in Risk Management Practices. <https://books.google.com/books/>
- Audinet JP, Baldrati T, Bonelli P, Cecilia G, Giacomo UD, Panuccio G, Battisti C (2021) Searching the effectiveness within conservation projects: Applying the Swiss Cheese Theory to the creation of a supplementary feeding station for the Black Kite *Milvus migrans* in central Italy. *Avocetta* 45(2). <https://doi.org/10.30456/AVO.2021206>
- Aust J, Pons D (2020) A systematic methodology for developing bowtie in risk assessment: application to borescope inspection. *Aerospace* 7(7):86 (<https://www.mdpi.com/2226-4310/7/7/86>)
- Azadegan A, Srinivasan R, Blome C, Tajeddini K (2019) Learning from near-miss events: An organizational learning perspective on supply chain disruption response. *Int J Prod Econ* 216:215–226. <https://doi.org/10.1016/j.ijpe.2019.04.021>
- Battisti C (2018) Why is it so difficult to have success? Applying the Swiss Cheese theory to environmental practices. *Environ Pract* 20(2–3):42–54. <https://doi.org/10.1080/14660466.2018.1489185>
- Bialystok E (2021) Bilingualism as a slice of Swiss cheese. *Front Psychol* 12:5219. <https://doi.org/10.3389/fpsyg.2021.769323>
- Bijay B, George P, Renjith VR, Kurian AJ (2020) Application of dynamic risk analysis in offshore drilling processes. *J Loss Prev Process Ind* 68:104326. <https://doi.org/10.1016/j.jlp.2020.104326>
- Buist M, Arnold G (2022) Clinical Futile Cycles: Systematic Micro-economic Reform of Health Care by Reform of the Traditional Hierarchical Referral Model of Care. In *Contemporary Topics in Patient Safety-Volume 2*. IntechOpen. DOI: <https://doi.org/10.5772/intechopen.106034>
- Chandra, S. (2023). Keep It Simple but not Stupid—Complex Technology and Complex Organisations. In *Accidents and Disasters: Lessons from Air Crashes and Pandemics* (pp. 51–69). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-19-9984-0_4
- Cheshmberah M, Naderizadeh A, Shafaghat A, Nokabadi M (2020) An integrated process model for root cause failure analysis based on reality charting, FMEA and DEMATEL. *Int J Data Netw Sci* 4(2):225–236. <https://doi.org/10.5267/j.ijdns.2019.12.003>
- Chigara B, Moyo T (2022) Factors affecting the delivery of optimum health and safety on construction projects during the covid-19 pandemic in Zimbabwe. *J Eng Design Technol* 20(1):24–46. <https://doi.org/10.1108/JEDT-01-2021-0053>
- Chimwai L, Munyanyi W (2019) Risk attitude, risk perception and risk management strategies adoption in Zimbabwean small and medium enterprises. *J Manag Econ Stud* 1(2):53–68 (<https://jomaes.org/index.php/jomaes/article/view/15>)
- Cohen TN, Francis SE, Wiegmann DA, Shappell SA, Gewertz BL (2018) Using HFACS-healthcare to identify systemic vulnerabilities during surgery. *Am J Med Qual* 33:614–622. <https://doi.org/10.1177/1062860618764316>
- da Cunha DT, Hakim MP, Soon JM, Stedefeldt E (2022) Swiss Cheese Model of food safety incidents: Preventing foodborne illness through multiple layers of defence. *Food Control* 139:109053. <https://doi.org/10.1016/j.foodcont.2022.109053>
- Darabont DC, Badea DO, Trifu A (2020) Comparison of four major industrial disasters from the perspective of human error factor. In *MATEC Web of Conferences* (Vol. 305, p. 00017). EDP Sciences. <https://doi.org/10.1051/mateconf/202030500017>
- de Sant DALM, de Hilal AVG (2021) The impact of human factors on pilots' safety behavior in offshore aviation companies: A Brazilian case. *Saf Sci* 140:105272. <https://doi.org/10.1016/j.ssci.2021.105272>
- Degefu GM (2021) Using Aggregated Industry Accident Data, Bayesian Belief Network, and Human Reliability Analysis to Better Predict Human Error Probability in Aviation. <https://search.proquest.com/openview/92816e13be658ea504ba8998b96277ab/1?pq-origsite=gscholar&cbl=18750&diss=y>
- Ding R, Liu Z, Xu J, Meng F, Sui Y, Men X (2021) A novel approach for reliability assessment of residual heat removal system for HPR1000 based on failure mode and effect analysis, fault tree analysis, and fuzzy Bayesian network methods. *Reliab Eng Syst Saf* 216:107911. <https://doi.org/10.1016/j.ress.2021.107911>
- Ebrahimi H, Sattari F, Lefsrud L, Macciotta R (2021) Analysis of train derailments and collisions to identify leading causes of loss incidents in rail transport of dangerous goods in Canada. *J Loss Prev Process Ind* 72:104517. <https://doi.org/10.1016/j.jlp.2021.104517>
- Elsehrawy MG, Mohamed Abd Elhady TR, Othman WN (2021) Effect of modified Swiss cheese model on patient safety, patient safety culture, and medication errors among nursing students. *Assiut Sci Nurs J* 9(27):1–10. <https://doi.org/10.21608/asnj.2021.94208.1233>
- Evans M, He Y, Maglaras L, Yevseyeva I, Janicke H (2019) Evaluating information security core human error causes (IS-CHEC) technique in public sector and comparison with the private sector. *Int J Med Informatics* 127:109–119. <https://doi.org/10.1016/j.ijmedinf.2019.04.019>
- Fan CL (2020) Defect risk assessment using a hybrid machine learning method. *J Constr Eng Manag* 146(9):04020102. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0001897](https://doi.org/10.1061/(ASCE)CO.1943-7862.0001897)
- Filyppova S, Kholod B, Prodanova L, Ivanchenkova L, Ivanchenkov V, Bashynska I (2019) Risk management through systematization: Risk management culture. <http://dspace.opu.ua/jspui/handle/123456789/8913>
- Fu G, Xie X, Jia Q, Li Z, Chen P, Ge Y (2020) The development history of accident causation models in the past 100 years: 24Model, a more modern accident causation model. *Process Saf Environ Prot* 134:47–82. <https://doi.org/10.1016/j.psep.2019.11.027>
- Fuad AFA, Said MH, Samo K, Mohd MH, Zainol I (2019) Proposed Improvement on Availability of Sarawak Marine Aids to Navigations by Using FSA And Swiss Cheese Model. *J Marit Res* 16(3):14–25 (<https://www.jmr.unican.es/index.php/jmr/article/view/566>)
- Goddu GC (2021) A simple theory of argument schemes. *Informal Logic* 41(4):539–578. <https://doi.org/10.22329/il.v41i4.6671>
- González Barman K (2023) Accident Causation Models: The Good the Bad and the Ugly. *Eng Stud* 1–26. <https://doi.org/10.1080/19378629.2023.2205024>
- Green SD (2023) The Nature of Accidents. In *Pilot Competency and Capability*. Taylor & Francis. <https://library.oapen.org/handle/20.500.12657/62009>
- Gwezuvu N, Jerie (2018) Safety and health problems in the small and medium scale metal fabrication enterprises in Willowvale Industrial Area in Harare, Zimbabwe. *Am J Human Soc Sci Res (AJHSSR)* 2(10):7 (http://www.ajhssr.com/wp-content/uploads/cfdb7_uploads/1532968396)

- Hald EJ, Gillespie A, Reader TW (2021) Causal and corrective organizational culture: A systematic review of case studies of institutional failure. *J Bus Ethics* 174:457–483. <https://doi.org/10.1007/s10551-020-04620-3>
- Hao M, Nie Y (2022) Hazard identification, risk assessment and management of industrial system: Process safety in mining industry. *Saf Sci* 154:105863. <https://doi.org/10.1016/j.ssci.2022.105863>
- Holtermann JVH (2021) In Defence of a Metaphor: A Reply to Shai Dothan's Critique of Applying the Swiss Cheese Model on Deterrence to the International Criminal Court. *J Int Crim Justice* 19(4):893–912. <https://doi.org/10.1093/jicj/mqab025>
- Hsu WKK, Shu MH, Liu YC, Wang TC (2022) Risk Management of Safety for Flight Training in Air Forces. *Aerospace* 9(10):558 (<https://www.mdpi.com/2226-4310/9/10/558>)
- Ibrahim H, Patruni JR (2019) Bayesian network-based failure analysis of fire safety barriers in floating LNG facility. *SN Appl Sci* 1:1–17. <https://doi.org/10.1007/s42452-019-1106-z>
- Jerie S, Jenya B (2017) The effectiveness of behaviour based safety (BBS) in accident prevention at a pine timber processing plant in Nyanga District, Zimbabwe. *Rev Soc Sci* 2(6), 1–10. <https://doi.org/10.18533/rss.v2i6.103>
- Jerie S, Matunhira K (2022) Occupational safety and health hazards associated with the slaughtering and meat processing industry in urban areas of Zimbabwe: A case study of the Gweru city Municipal Abattoir. *Ghana J Geogr* 14(1). <https://doi.org/10.4314/gjg.v14i1.2>
- Jerie S, Musasa T (2022) Solid waste management and the Covid 19 pandemic lockdown in Zvishavane town, Zimbabwe. *Ethiopian J Environ Stud Manag* 15(3). <https://ejesm.org/doi/v15i3.5>
- Jing L, Bai Q, Guo W, Feng Y, Liu L, Zhang Y (2020) Contributory factors interactions model: A new systems-based accident model. *Syst Res Behav Sci* 37(2):255–276. <https://doi.org/10.1002/sres.2618>
- Jong JC, Lai YC, Young CC, Chen YF (2020) Application of fault tree analysis and Swiss cheese model to the over speed derailment of Puyuma Train in Yilan Taiwan. *Transport Res Record* 2674(5):33–46. <https://doi.org/10.1177/0361198120914887>
- Jung S, Woo J, Kang C (2020) Analysis of severe industrial accidents caused by hazardous chemicals in South Korea from January 2008 to June 2018. *Saf Sci* 124:104580. <https://doi.org/10.1016/j.ssci.2019.104580>
- Kadena E, Keszthelyi A (2022) Identifying Failures in Mobile Devices. *Interdiscip Description Complex Syst: INDECS* 20(3):222–229
- Kamoun F, Nicho M (2018) A new perspective on the Swiss cheese model applied to understanding the anatomy of healthcare data breaches. In *Handbook of Research on Emerging Perspectives on Healthcare Information Systems and Informatics* (pp. 58–81). IGI Global. DOI: <https://doi.org/10.4018/978-1-5225-5460-8.ch004>
- Karanikas N (2022) How could investigators use safety models to inform decisions on what to focus on? In *ISASI Conference 2022* (Technical Papers). International Society of Air Safety Investigators. <https://eprints.qut.edu.au/235252>
- Karimi A, Abbasi M, Zokaei M, Falahati M (2021) Development of leading indicators for the assessment of occupational health performance using Reason's Swiss cheese model. *J Educ Health Promotion*. https://doi.org/10.4103/jehp.jehp_1326_20
- Kim JY, Boag W, Gulamali F, Hasan A, Hogg HDJ, Lifson M, Sendak M (2023) Organizational Governance of Emerging Technologies: AI Adoption in Healthcare. In *Proceedings of the 2023 ACM Conference on Fairness, Accountability, and Transparency* (pp. 1396–1417). <https://doi.org/10.1145/3593013.3594089>
- Kirwan B, Bettignies-Thiebaut B, Cocchioni M, Baumler R, Carrera Arce M (2021) Towards a safety learning culture for the shipping industry: a white paper. https://commons.wmu.se/cgi/viewcontent.cgi?article=1000&context=lib_documents
- Larouze J, Le Coze JC (2020) Good and bad reasons: The Swiss cheese model and its critics. *Saf Sci* 126:104660. <https://doi.org/10.1016/j.ssci.2020.104660>
- Leksir A (2020) Oil well casing cement flash setting problem causes and identification strategy based on cheese model. *J Pet Explor Prod Technol* 10:3363–3376. <https://doi.org/10.1007/s13202-020-00882-9>
- Lewandowski J, Ma Y, Yang J, Zhang C (2023) Quantum Oppenheimer-Snyder and Swiss cheese models. *Phys Rev Lett* 130(10):101501. <https://doi.org/10.1103/PhysRevLett.130.101501>
- Lin Y, Liu X, Yang Y, Sun H, Zhang D (2023) Check for updates Research on Defence-in-Depth of Nuclear Power Plant DCS Based on Swiss Cheese Model. In *New Energy Power Generation Automation and Intelligent Technology: Proceedings of the Seventh Seminar on Digital Instrumentation and Control Technology for Nuclear Power Plant* (Vol. 1055, p. 310). Springer Nature. https://doi.org/10.1007/978-981-99-3455-3_31
- Liou JJ, Liu PC, Luo SS, Lo HW, Wu YZ (2022) A hybrid model integrating FMEA and HFACS to assess the risk of inter-city bus accidents. *Complex Intell Syst* 8(3):2451–2470. <https://doi.org/10.1007/s40747-022-00657-1>
- Logrosa G, Mata MA, Lachica ZP, Estaña LM, Hassall M (2022) Integrating risk assessment and decision-making methods in Analyzing the dynamics of COVID-19 epidemics in Davao City, Mindanao Island Philippines. *Risk Anal* 42(1):105–125. <https://doi.org/10.1111/risa.13779>
- Loh TY, Brito MP, Bose N, Xu J, Tenekedjiev K (2020) Human error in autonomous underwater vehicle deployment: a system dynamics approach. *Risk Anal* 40(6):1258–1278. <https://doi.org/10.1111/risa.13467>
- Lu W (2021) Analysis of human factors in ship collisions based on accident investigation reports. https://commons.wmu.se/cgi/viewcontent.cgi?article=1307&context=msem_dissertations
- Ma X, Deng W, Qiao W, Lan H (2022) A methodology to quantify the risk propagation of hazardous events for ship grounding accidents based on directed CN. *Reliab Eng Syst Saf* 221:108334. <https://doi.org/10.1016/j.res.2022.108334>
- Mabika B (2018) Improving workers' safety and health in the Zimbabwean mining and quarrying industry. <https://scholarworks.walderu.edu/cgi/viewcontent.cgi?article=6778&context=dissertations>
- Mapuvire DH, Chilunjika SR, Mutasa F (2022) The Health and Safety Perspectives in the Zimbabwe Public Sector. In *Transformational Human Resources Management in Zimbabwe: Solutions for the Public Sector in the 21st Century* (pp. 167–185). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-19-4629-5_11
- Maskari ZA, Tai AA, Kindi HA, Busaidi AA, Mammari KA, Shukri IA, Waili BA (2023) Health care-associated measles outbreak in pediatric wards in a tertiary care hospital: Challenges and Swiss cheese model enforcement for patient safety. *Am J Infect Control*. <https://doi.org/10.1016/j.ajic.2023.02.011>
- Mavhura E (2019) A systems approach for assessing emergency preparedness in underground mines of Zimbabwe. *Resour Policy* 62:1–8. <https://doi.org/10.1016/j.resourpol.2019.03.005>
- Mendes N, Vieira JGV, Mano AP (2022) Risk management in aviation maintenance: A systematic literature review. *Saf Sci* 153:105810. <https://doi.org/10.1016/j.ssci.2022.105810>
- Mkungunugwa T, Owili PO, Muula AS, Kuo HW (2022) Implementation determinants of Zimbabwe National occupational safety and health policy in willowvale industrial area, Zimbabwe. *Int J Environ Res Public Health* 19(3):1424
- Mohammadfam I, Khajevandi AA, Dehghani H, Babamiri M, Farhadian M (2022) Analysis of factors affecting human reliability in the mining process design using Fuzzy Delphi and DEMATEL methods. *Sustainability* 14(13):8168 (<https://www.mdpi.com/2071-1050/14/13/8168>)

- Munir M, Jajja MSS, Chatha KA, Farooq S (2020) Supply chain risk management and operational performance: The enabling role of supply chain integration. *Int J Prod Econ* 227:107667. <https://doi.org/10.1016/j.ijpe.2020.107667>
- Musabayana I, Mandizvidza T, Mutongi C, Nyoni SP, Nyoni T (2021) An analysis of factors contributing to high occupational accident prevalence rate at Zimbabwe electricity transmission distribution company (ZETDC) Northern Region, Chinhoyi, Zimbabwe. *Int Res J Innov Eng Technol* 5(3), 441. <https://doi.org/10.47001/IRJIET/2021.503076>
- Musungwa T, Kowe P (2022) Effects of occupational health and safety management systems implementation in accident prevention at a Harare beverage company. *Cogent Eng* 9(1):2124638. <https://doi.org/10.1080/23311916.2022.2124638>
- Nkosi M, Gupta K, Mashinini M (2020) Causes and impact of human error in maintenance of mechanical systems. In *MATEC Web of Conferences* (Vol. 312, p. 05001). EDP Sciences. <https://doi.org/10.1051/mateconf/202031205001>
- Noh JY, Song JY, Yoon JG, Seong H, Cheong HJ, Kim WJ (2020) Safe hospital preparedness in the era of COVID-19: The Swiss cheese model. *Int J Infect Dis* 98:294–296. <https://doi.org/10.1016/j.ijid.2020.06.094>
- Norazahar NB (2020) Human factors risk assessment. In *Methods in Chemical Process Safety* (Vol. 4, pp. 289–302). Elsevier. <https://doi.org/10.1016/bs.mcps.2020.02.005>
- Nunu WN, Kativhu T, Moyo P (2018) An evaluation of the effectiveness of the Behaviour Based Safety Initiative card system at a cement manufacturing company in Zimbabwe. *Saf Health Work* 9(3):308–313. <https://doi.org/10.1016/j.shaw.2017.09.002>
- Olson JA, Raz A (2021) Applying insights from magic to improve deception in research: The Swiss cheese model. *J Exp Soc Psychol* 92:104053. <https://doi.org/10.1016/j.jesp.2020.104053>
- Pan K, Liu H, Gou X, Huang R, Ye D, Wang H, Kong J (2022) Towards a Systematic Description of Fault Tree Analysis Studies Using Informetric Mapping. *Sustainability* 14(18):11430 (<https://www.mdpi.com/2071-1050/14/18/11430>)
- Puthillath B, Marath B, Ayappan BC (2023) Analyzing the cause of human electrical accidents using Swiss Cheese model. *Vilakshan-XIMB J Manag* 20(1):193–208. <https://doi.org/10.1108/XJM-01-2021-0004>
- Qiao W, Liu Y, Ma X, Liu Y (2020) A methodology to evaluate human factors contributed to maritime accident by mapping fuzzy FT into ANN based on HFACS. *Ocean Eng* 197:106892. <https://doi.org/10.1016/j.oceaneng.2019.106892>
- Raharjo EP, Putra Adidana I, Candrarahayu AM (2023) Swiss Cheese Model for Analyzing Freight Car and Bus Traffic Accidents can Lead to the Implementation of Preventive Measures for Traffic Accident Avoidance. *Pak J Life Soc Sci* 21(1). <https://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=17274915&AN=164603491&h=4huP1st55%2BKzxU95CpLcrORz6Cq09FzwUQm8tqSYtZjKwo1yFbKrwGEE907wI5%2BFteE1Rp2E04wSqtS1EEzzg%3D%3D&crl=c>
- Saeidi Keshavarz M, Razavian F, Namjoufar S, Zahed MA (2020) A new conceptual model for quantitative fire risk assessment of oil storage tanks in the Tehran refinery, Iran. *Environ Energy Econ Res* 4(3), 241–249. <https://doi.org/10.22097/eeer.2020.176948.1074>
- Santos RB, de Oliveira UR (2019) Analysis of occupational risk management tools for the film and television industry. *Int J Ind Ergon* 72:199–211. <https://doi.org/10.1016/j.ergon.2019.05.002>
- Sarin A, Bhatnagar V, Neelakantan A, Khandare M (2020) Best practices with optimal outcomes during COVID-19 pandemic-A swiss cheese model experiment in the naval training command. *Journal of Marine Medical Society* 22(2):266–266 (<https://go.gale.com/ps/i.do?id=GALE%7CA649587315&sid=goog>
- [eScholar&v=2.1&it=r&linkaccess=abs&issn=09753605&p=AONE&sw=w](https://doi.org/10.1016/j.ijpe.2020.107667))
- Sehgal T (2023) Human Error in an Automated Laboratory. *J Patient Saf* 10–1097. <https://doi.org/10.1097/PTS.0000000000001143>
- Seshia SS, Bryan Young G, Makhinson M, Smith PA, Stobart K, Croskerry P (2018) Gating the holes in the Swiss cheese (Part I): Expanding professor Reason's model for patient safety. *J Eval Clin Pract* 24(1):187–197. <https://doi.org/10.1111/jep.12847>
- Shabani T, Jerie S, Shabani T (2023) A review of the role of Behaviour-Based Procedures in work safety analysis in the Medical Sector of Zimbabwe. *Life Cycle Reliability and Safety Engineering*, 1–16. <https://doi.org/10.1007/s41872-023-00227-5>
- Shabani T, Jerie S, Shabani T (2023) Assessment of work-related risks among healthcare workers in rural hospitals of Chirumanzu District, Zimbabwe. *Safety Extreme Environ* 1–18. <https://doi.org/10.1007/s42797-023-00075-7>
- Shabani T, Jerie S, Shabani T (2023) Occupational stress among workers in the health service in Zimbabwe: causes, consequences and interventions. *Saf Extreme Environ* 1–12. <https://doi.org/10.1007/s42797-023-00084-6>
- Shabani T, Jerie S, Shabani T (2023d) The effectiveness of total loss control approach in accident prevention in industries in Zimbabwe. *Life Cycle Reliab Saf Eng* 12:93–109. <https://doi.org/10.1007/s41872-023-00222-w>
- Shabani T, Jerie S, Shabani T (2023) The impact of occupational safety and health programs on employee productivity and organisational performance in Zimbabwe. *Saf Extreme Environ* 1–12. <https://doi.org/10.1007/s42797-023-00083-7>
- Shahid N, Rappon T, Berta W (2019) Applications of artificial neural networks in health care organizational decision-making: A scoping review. *PLoS ONE* 14(2):e0212356. <https://doi.org/10.1371/journal.pone.0212356>
- Sheehan B, Murphy F, Kia AN, Kiely R (2021) A quantitative bow-tie cyber risk classification and assessment framework. *J Risk Res* 24(12):1619–1638. <https://doi.org/10.1080/13669877.2021.1900337>
- Siegrist M, Luchsinger L, Bearth A (2021) The impact of trust and risk perception on the acceptance of measures to reduce COVID-19 cases. *Risk Anal* 41(5):787–800. <https://doi.org/10.1111/risa.13675>
- Singo J, Isunju JB, Moyo D, Bose-O'Reilly S, Steckling-Muschack N, Mamuse A (2022) Accidents, injuries, and safety among artisanal and small-scale gold miners in Zimbabwe. *Int J Environ Res Public Health* 19(14):8663 (<https://www.mdpi.com/1660-4601/19/14/8663>)
- Singo J, Isunju JB, Moyo D, Steckling-Muschack N, Bose-O'Reilly S, Mamuse A (2022) Hazards and control measures among artisanal and small-scale gold miners in Zimbabwe. *Ann Global Health* 88(1). <https://doi.org/10.5334/aogh.3621>
- Singo J, Moyo D, Isunju JB, Bose-O'Reilly S, Steckling-Muschack N, Becker J, Mamuse A (2022) Health and safety risk mitigation among artisanal and small-scale gold miners in Zimbabwe. *Int J Environ Res Public Health* 19(21):14352 (<https://www.mdpi.com/1660-4601/19/21/14352>)
- Smith AF, Plunkett E (2019) People, systems and safety: resilience and excellence in healthcare practice. *Anaesthesia* 74(4):508–517. <https://doi.org/10.1111/anae.14519>
- Song W, Li J, Li H, Ming X (2020) Human factors risk assessment: An integrated method for improving safety in clinical use of medical devices. *Appl Soft Comput* 86:105918. <https://doi.org/10.1016/j.asoc.2019.105918>
- Stosic K, Dahlstrom N, Boonchai C (2022) Applying lessons from aviation safety culture in the hospitality industry: a review and road map. *Int J Occup Saf Ergon* 1–12. <https://doi.org/10.1080/10803548.2022.2108638>

- Taherdoost H (2021) A review on risk management in information systems: Risk policy, control and fraud detection. *Electronics* 10(24):3065. <https://doi.org/10.3390/electronics10243065>
- Thonon H, Espeel F, Frederic F, Thys F (2019) Overlooked guide wire: a multicomplexed Swiss Cheese Model example. Analysis of a case and review of the literature. *Acta Clinica Belgica*. <https://doi.org/10.1080/17843286.2019.1592738>
- Torres Y, Nadeau S, Landau K (2022) Applying AcciMap and STAMP to the analysis of human error in complex manual assembly. *Human Factors Ergon Manuf Serv Ind* 32(6):462–481. <https://doi.org/10.1002/hfm.20964>
- Toto GA, Limone P (2019) Road transport accident analysis from a system-based accident analysis approach using Swiss cheese model. *Int J Eng Educ* 1(2), 99–105. <https://doi.org/10.14710/ijee.1.2.99-105>
- United States Bureau of Labour Statistics (2018) National census of fatal occupational injuries in 2017. Occupational injuries in 2017. <https://www.bing.com/ck/a?>
- Van der Schaar M, Alaa AM, Floto A, Gimson A, Scholtes S, Wood A, Ercole A (2021) How artificial intelligence and machine learning can help healthcare systems respond to COVID-19. *Mach Learn* 110:1–14. <https://doi.org/10.1007/s10994-020-05928-x>
- Van Thuyet N, Ogunlana SO, Dey PK (2019) Risk management in oil and gas construction projects in Vietnam. In *Risk Management in Engineering and Construction* (pp. 225–247). Routledge. <https://www.taylorfrancis.com/chapters/edit/https://doi.org/10.4324/9780203887059-13>
- Warner J, Alves EN, Coates R (2019) Swiss cheese in Brazil: disaster culture and safety culture in disasters. *Ambiente and Sociedade* 22:e0004. <https://doi.org/10.1590/1809-4422asoc2019Ex0004vu2019L3ID>
- Wegman F (2021) Sustainable Safety: The Dutch Example of a Safe System Approach. *Transport and Safety: Systems, Approaches, and Implementation*, 29–51. https://doi.org/10.1007/978-981-16-1115-5_2
- Wen JX, Marono M, Moretto P, Reinecke EA, Sathiah P, Studer E, Melideo D (2022) Statistics, lessons learned and recommendations from analysis of HIAD 2.0 database. *Int J Hydrogen Energy* 47(38):17082–17096. <https://doi.org/10.1016/j.ijhydene.2022.03.170>
- Wiegmann DA, Wood LJ, Cohen TN, Shappell SA (2022) Understanding the “Swiss Cheese Model” and its application to patient safety. *J Patient Saf* 18(2):119–123. <https://doi.org/10.1097/PTS.0000000000000810>
- Wolf L, Parker SH, Gleason JL (2021) Human factors in healthcare. *Patient Safety and Quality Improvement in Healthcare: A Case-Based Approach*, 319–333. https://doi.org/10.1007/978-3-030-55829-1_20
- Wu B, Yip TL, Yan X, Soares CG (2022) Review of techniques and challenges of human and organizational factors analysis in maritime transportation. *Reliab Eng Syst Saf* 219:108249. <https://doi.org/10.1016/j.ress.2021.108249>
- Wu Y, Fu G, Wu Z, Wang Y, Xie X, Han M, Lyu Q (2023) A popular systemic accident model in China: theory and applications of 24Model. *Saf Sci* 159:106013. <https://doi.org/10.1016/j.ssci.2022.106013>
- Xiao Q, Li Y, Luo F, Liu H (2023) Analysis and assessment of risks to public safety from unmanned aerial vehicles using fault tree analysis and Bayesian network. *Technol Soc* 73:102229. <https://doi.org/10.1016/j.techsoc.2023.102229>
- Xie Z, Peng B (2023) A Framework for Resilient City Governance in Response to Sudden Weather Disasters: A Perspective Based on Accident Causation Theories. *Sustainability* 15(3):2387. <https://doi.org/10.3390/su15032387>
- Yalcin E, Ciftcioglu GA, Guzel BH (2023) Human Factors Analysis by Classifying Chemical Accidents into Operations. *Sustainability* 15(10):8129. <https://doi.org/10.3390/su15108129>
- Yazdi M, Mohammadpour J, Li H, Huang HZ, Zarei E, Pirbalouti RG, Adumene S (2023) Fault tree analysis improvements: a Bibliometric analysis and literature review. *Qual Reliab Eng Int* 39:1639–1659. <https://doi.org/10.1002/qre.3271>
- Yeow JA, Ng PK, Tai HT, Chow MM (2020) A Review on Human Error in Malaysia Manufacturing Industries. *Management* 5(19):01–13 (<https://www.researchgate.net/profile/JianYeow/publication/346580928>)
- Young MS, Shorrock ST, Faulkner JP (2023) Taste preferences of transport safety investigators: Who doesn't like Swiss cheese? In *Contemporary Ergonomics 2005* (pp. 392–396). Taylor and Francis. <https://www.taylorfrancis.com/chapters/edit/https://doi.org/10.1201/9781003419969-88>
- Yuan S, Reniers G, Yang M (2023) Dynamic-risk-informed safety barrier management: An application to cost-effective barrier optimization based on data from multiple sources. *J Loss Prev Process Ind* 83:105034. <https://doi.org/10.1016/j.jlp.2023.105034>
- Yuan S, Yang M, Reniers G, Chen C, Wu J (2022) Safety barriers in the chemical process industries: A state-of-the-art review on their classification, assessment, and management. *Saf Sci* 148:105647. <https://doi.org/10.1016/j.ssci.2021.105647>
- Zhang L, Chen J, Zhang Y, Xingchen Y (2019) The Best Practice of Safety performance management in Airlines. In *2019 5th International Conference on Transportation Information and Safety (ICTIS)* (pp. 778–788). IEEE. <https://ieeexplore.ieee.org/abstract/document/8883856>
- Zhao H, Yang Y, He X (2021). Safety Net Model: Grid-Based HSE Risk Management Integration with Twin Orientations. In *Abu Dhabi International Petroleum Exhibition and Conference (p. D041S118R004)*. SPE. <https://doi.org/10.2118/208014-MS>

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.