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Innovating Safety Risk Assessment in Large-Scale Manufacturing Enterprises: A Holistic Approach

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Abstract:

This research paper presents an innovative and comprehensive approach to safety risk evaluation in large-scale manufacturing enterprises in Ethiopia. The study uses in-depth literature reviews for identifying and categorizing safety risk factors, emphasizing the importance of safety, and evaluating the likelihood and consequences of risks. The proposed approach combines qualitative and quantitative methodologies; this innovative approach sets this study apart by providing a holistic and robust framework for safety risk assessment.

The findings of the study highlight the critical significance of major safety risks in the manufacturing industry. These findings underscore the importance of addressing issues such as worker behavior, training, equipment maintenance, and safety protocols. Based on the study's outcomes, practical implications for risk prioritization and management in large-scale manufacturing enterprises emerge. The methodologies proposed in this study empower manufacturing enterprises to develop proactive risk management strategies tailored to their specific contexts. This study's practical insights aid in reducing accidents, injuries, and environmental damage, contributing to improved overall performance and productivity.

In conclusion, this study presents an innovative and comprehensive approach to safety risk assessment in Ethiopian large-scale manufacturing enterprises. The study's key findings highlight the critical safety risks in the manufacturing industry, emphasizing the need for targeted risk reduction strategies. The practical implications of this research offer valuable guidance for risk prioritization and management, enabling companies to create safer work environments and improve their overall safety performance. The findings contribute to theory development and emphasize the importance of proactive risk management practices in the manufacturing industry.

Keywords: Safety Risk, Risk Identification, Risk Assessment, Comprehensive Approaches, Large- Scale Manufacturing Enterprises.

I. INTRODUCTION

In recent years, there has been a growing appreciation for the value of safety risk assessment in large-scale manufacturing enterprises. With the increasing complexity of manufacturing processes, the use of new technologies, and the possibility of catastrophic accidents, it is critical to identify, assess, and manage safety risks effectively [1]. The goal of risk assessment is to systematically identify and understand risks, allowing for informed decision-making and providing insights for developing risk management strategies [2]. Research conducted worldwide has consistently highlighted the importance of proactive safety risk management in the manufacturing industry [3]. Comprehensive overviews and trends in the field demonstrate that accidents and safety incidents not only cause human suffering but also have profound economic and social consequences [4]. Workers' well-being, productivity, and overall business performance are all dependent on effective safety risk assessment and management strategies [5].

According to the International Labour Organization (ILO), occupational accidents and diseases cause millions of fatalities and non-fatal injuries each year [6]. The manufacturing industry, with its complex machinery, hazardous materials, and high-risk work environments, is especially susceptible to such incidents. These accidents not only cause enormous human suffering but also impose significant costs on businesses and economies as a whole [7].

Risk assessment methodologies and safety management systems (SMS) are now standard practice in many manufacturing enterprises around the world. International organizations and regulatory bodies have emphasized the importance of systematic and structured approaches to identifying, assessing, and managing safety risks [8]. These approaches not only help to prevent accidents, but they also play an important role in ensuring compliance with safety regulations and standards. Methodologies for risk assessment include the

systematic identification and analysis of potential risks, their severity and likelihood, as well as the development of control or elimination strategies [9].

Safety management systems (SMS) offer a comprehensive framework for identifying, assessing, and managing safety risks in large-scale manufacturing enterprises, as illustrated in Figure 2.1. These systems typically include policies, procedures, and training programs aimed at increasing safety and reducing the likelihood of accidents. A properly implemented SMS not only ensures compliance with safety regulations but also fosters a proactive safety culture within the organization [10]. By incorporating safety considerations into all levels of decision-making, SMS fosters a shared understanding of safety responsibilities among employees, improving overall safety performance [11].

Furthermore, studies have demonstrated the importance of safety culture in large-scale manufacturing enterprises. A positive safety culture, characterized by strong leadership commitment, employee engagement, and continuous improvement efforts, has been linked to improved safety performance and lower accident rates [12]. Organizations with a strong safety culture prioritize safety in all aspects of their operations, promote open communication about safety issues, and empower employees to actively identify and mitigate risks [13]. Building a strong safety culture necessitates a thorough understanding of safety risk factors and effective assessment methods to prioritize and address them [14]. Quantitative risk analysis techniques, such as risk matrices and maps, have proven to be useful tools for evaluating safety risks. These tools help decision-makers assess the likelihood and consequences of risks, as well as provide a structured approach to ranking risk severity. However, recent research has emphasized the importance of considering both tangible and intangible consequences when evaluating risks [15].

As a result, a comprehensive approach to safety risk assessment should consider a wide range of factors, including human, machinery, material, management, and environmental concerns [16]. In addition to assessing the direct effects of accidents, safety risk assessments should take into account the broader social and economic consequences, as illustrated in Figure 2.2. Accidents and injuries in large-scale manufacturing facilities can have far-reaching consequences for employees, their families, and the communities in which they operate [17].

Safety risk assessment is especially important in large-scale manufacturing enterprises in developing countries like Ethiopia. These businesses frequently face unique challenges, such as limited resources, inadequate infrastructure, and a lack of safety regulation enforcement. Improving safety risk evaluation in such situations necessitates tailored strategies that address the specific needs and constraints of these businesses while also protecting workers, communities, and the environment. This study seeks to provide a comprehensive approach to safety risk assessment in large-scale manufacturing enterprises. To summarize, the value of safety risk assessment in large-scale manufacturing enterprises cannot be overstated. Organizations must take a comprehensive approach that includes risk assessment methodologies, safety management systems, and a strong safety culture. Organizations can reduce risks and improve overall safety performance by prioritizing worker safety, protecting the environment, and addressing the unique challenges faced by large-scale manufacturing enterprises. It is the paper's best contribution. This study is critical for policymakers, investors, and practitioners in Africa because it validates the system theory in a large-scale manufacturing context and emphasizes the significance of safety performance in the manufacturing industry throughout the African continent, more specifically in Ethiopia, and contributes to sustainable development, and the study supports system theory.

2. CONCEPTUAL AND THEORETICAL FRAMEWORK

2.1 Theoretical Foundations

System Theory

Systems theory provides a comprehensive and appealing theoretical foundation for safety risk management in large-scale manufacturing operations. It provides a comprehensive understanding of organizations' complex and interconnected nature, emphasizing the importance of considering multiple elements in risk management efforts. In systems theory, organizations are viewed as dynamic systems made up of various components that interact with one another. People, processes, technology, and the environment are all part of this equation. Each component contributes to the overall operation of the system, and their interactions can pose safety risks [18]. People play an important role in the system because their actions, decisions, and behaviors have a direct impact on safety. Human error, lack of training, and inadequate communication are factors that can contribute to safety risks. Understanding the human component of the system allows organizations to implement strategies such as training programs, open communication channels, and effective leadership to foster a safety-conscious culture [19].

Manufacturing procedures, maintenance protocols, and emergency response plans are all examples of organizational processes that have an impact on safety. More efficient and well-designed processes can introduce hazards and raise the risk of accidents. Using systems thinking, organizations can identify potential weaknesses in processes and implement improvements to mitigate risks [20]. Technology, including machinery and equipment, is another important component of the system. Malfunctioning equipment, inadequate maintenance,

and out-of-date technology can all pose safety risks. Organizations that consider the technological aspect of the system can ensure proper maintenance, implement safety features, and use advanced technologies to improve safety and reduce risks [21].

The organization's operating environment is also important. Physical hazards, weather conditions, and external influences all have an impact on safety. Organizations must assess and manage environmental risks, which include providing safe working conditions, implementing appropriate safety measures, and adhering to regulatory requirements [22]. Organizations that adopt a systems perspective gain a thorough understanding of the interdependence and interactions between these components. This understanding enables a proactive approach to risk management by identifying potential hazards and implementing appropriate control measures at various levels of the system [23]. Furthermore, systems theory emphasizes the significance of feedback loops and ongoing improvement. Organizations can continuously monitor and evaluate the effectiveness of their risk management strategies, gather employee feedback, and make necessary changes to improve safety performance [24].

In conclusion, systems theory offers a comprehensive and appealing theoretical foundation for safety risk management in large-scale manufacturing enterprises. Organizations can effectively identify, assess, and mitigate safety risks by recognizing their interconnectedness with people, processes, technology, and the environment, resulting in a safer work environment and improved overall organizational performance.

2.2 Identification and Categorization of Safety Risk Factors

The safety risk factors are the identification process done by in-depth literature reviews and expert feedback in the context of Ethiopian large-scale manufacturing enterprises [25]. Based on these Ethiopian Large-scale manufacturing enterprises face a variety of safety risks, including human factors, machinery factors, material factors, management factors, and environmental factors [26]. Previous research has contributed significantly to identifying and understanding these risk factors in LSMEs. Human factors such as improper training, lack of safety awareness, fatigue, and poor mental health have been shown to increase risks in manufacturing facilities [27]. Machinery-related risks include unsafe equipment design, lack of machine guards or controls, and inadequate preventative maintenance programs [16].

When it comes to materials, risks may be posed by improper chemical handling, storage of flammable substances, and exposure to hazardous materials [28]. Management factors that have been linked to safety risks include insufficient safety policies and oversight, lack of near-miss reporting systems, and inadequate allocation of financial resources for safety [29]. The physical work environment also presents risks like unsafe building infrastructure, fire and electrical hazards, and exposure to noise and pollutants. The identification of safety risk factors is an important step in effective risk management. Organizations can develop targeted strategies to mitigate potential hazards and avoid accidents by identifying and categorizing these factors [9], as illustrated in Figure 2.2. Several studies have investigated the specific risk factors present in Large-scale manufacturing enterprises in Ethiopia, providing valuable insights into their classification and categorization [25,26].

Human Factors in Large-Scale Manufacturing Enterprises

Human factors significantly influence safety performance and risk management in large-scale manufacturing enterprises. These factors include a variety of elements, such as human error, a lack of training, fatigue, and ineffective communication. Understanding the impact of human factors on safety performance is critical for developing interventions and enhancing the safety culture in large-scale manufacturing enterprises [30] . Human error is a significant source of safety risks in LSMEs. It refers to mistakes or incorrect actions taken by individuals that can result in accidents or dangerous situations. Human errors can occur for a variety of reasons, including a lack of focus, insufficient knowledge or experience, distractions, and complacency. Identifying the underlying causes of human errors is critical for implementing preventive measures and developing training programs to reduce their occurrence [31]. Lack of training is another human factor that can contribute to safety hazards. Inadequate training programs or a lack of proper training can leave employees without the necessary skills and knowledge to complete their tasks safely. It can lead to errors, inefficiencies, and higher risks. Providing comprehensive and ongoing training programs that address specific job requirements and safety protocols is critical for reducing this risk [27]. Fatigue is a major concern among large-scale manufacturing enterprises, especially in industries that require shift work or long working hours. Fatigue can impair cognitive functioning, reaction times, and decision-making abilities, raising the risk of errors and accidents. Addressing fatigue-related risks requires implementing strategies such as optimizing work schedules, promoting adequate rest breaks, and raising awareness about their importance. Sleep and recovery [32]. Inadequate communication, a human factor, can impede effective safety management in manufacturing enterprises. Promoting open and effective communication within the organization, implementing clear protocols for reporting safety concerns, and cultivating a culture of transparency is critical for improving communication and lowering associated risks [33].

The effect of human factors on safety performance in large-scale manufacturing enterprises has been debated and discussed by researchers, safety professionals, and industry stakeholders. One debate focuses on the balance of individual responsibility and organizational factors in preventing human errors. The consensus is that addressing human factors and mitigating associated risks

requires a combination of individual and organizational efforts [34]. It stems from the recognition that multiple methods should be used to gain a thorough understanding of human factors and their impact on safety performance. Agreement exists regarding the importance of a strong safety culture in managing human factors and promoting safety in large-scale manufacturing enterprises. A positive safety culture promotes shared values, attitudes, and behaviors that prioritize safety while also empowering employees to actively participate in risk management. Building a strong safety culture necessitates leadership commitment, effective communication, employee engagement, and continuous improvement initiatives. By addressing human factors through these interventions and promoting a strong safety culture, LSMEs can improve safety performance, reduce accidents, and provide a safer working environment for their employees. Recognizing the significance of human factors and taking proactive measures to mitigate associated risks are essential steps toward achieving sustainable safety outcomes in large-scale manufacturing enterprises.

Machinery Factors in Large-Scale Manufacturing Enterprises

Machinery factors play a critical role in the safety performance and risk management of large-scale manufacturing enterprises. These factors encompass the design, maintenance, and operation of machinery and equipment within LSMEs. Faulty equipment, inadequate maintenance practices, and improper usage can significantly increase the risk of accidents and injuries. Identifying and addressing machinery-related risks is crucial for ensuring worker safety and preventing equipment failures [35]. The design of machinery and equipment is a fundamental aspect of ensuring safety in LSMEs. By considering human factors, ergonomics, and industry standards during the design phase, LSMEs can reduce the risk of accidents and create a safer working environment for their employees [36].

Maintenance practices play a vital role in ensuring the safe and reliable operation of machinery. Implementing a robust maintenance program that includes regular inspections, preventive maintenance, and prompt repairs is essential for minimizing machinery-related risks [37]. Proper operation of machinery is crucial for worker safety in LSMEs. Continuous training, regular refresher courses, and strict adherence to operating protocols are essential for mitigating these risks [38]. Identifying and addressing machinery-related risks requires a systematic approach within LSMEs. By understanding and evaluating these risks, we can implement appropriate control measures and safety protocols [16].

Preventive maintenance programs are essential to minimize machinery-related risks. Proactive maintenance practices significantly reduce the probability of equipment failures and subsequent accidents [39]. Employee involvement and feedback are crucial for effective machinery risk management. Encouraging open communication channels, implementing reporting systems for near-misses and equipment malfunctions, and involving employees in safety committees or risk assessments can contribute to a proactive safety culture and the identification of potential machinery-related risks [40]. By addressing machinery factors through proper design, comprehensive maintenance practices, and safe operation, LSMEs can significantly reduce the risk of accidents, injuries, and equipment failures. Investing in quality machinery, implementing robust maintenance programs, providing adequate training, and fostering a culture of safety are essential steps towards ensuring worker safety and creating a secure working environment within LSMEs. By prioritizing machinery-related risk management, LSMEs can achieve operational excellence while safeguarding the well-being of their employees.

Material Factors in Large-Scale Manufacturing Enterprises

Material factors are a critical aspect of safety performance and risk management in large-scale manufacturing enterprises. These factors involve the handling, storage, and transportation of hazardous materials within LSMEs. Inadequate safety measures in dealing with these substances can lead to chemical spills, fires, or explosions, posing severe risks to workers, the environment, and surrounding communities. Understanding the risks associated with materials used in manufacturing processes is vital for implementing appropriate safety protocols [41]. The handling of hazardous materials requires careful consideration and adherence to safety protocols. This knowledge allows for the implementation of appropriate handling procedures, such as using personal protective equipment (PPE), establishing designated storage areas, and implementing safe work practices to minimize the risk of exposure or accidents [42].

Proper storage of hazardous materials is crucial for preventing incidents and ensuring worker safety. LSMEs must provide dedicated storage areas that meet regulatory requirements and industry standards [43]. Transportation of hazardous materials within LSMEs requires special attention to prevent accidents and spills. Adequate training for employees involved in transportation activities is essential to ensure they understand the risks associated with the materials and are proficient in handling emergencies [44]. Understanding the risks associated with specific materials used in manufacturing processes is crucial for implementing appropriate safety protocols. It includes evaluating the toxicity, flammability, explosiveness, and other properties of the materials, as well as considering potential reactions with other substances present in the facility [45]. Implementing appropriate safety protocols for material factors requires comprehensive training programs for employees. Regular refresher training sessions and ongoing awareness campaigns can help reinforce safe practices and ensure that employees remain vigilant about material-related risks [46]. To minimize material-related risks,

LSMEs should establish a robust safety management system. Encouraging a culture of safety and accountability among employees is essential to ensure that safety protocols are followed consistently [47].

By addressing material factors through proper handling, storage, and transportation practices, LSMEs can significantly reduce the risks associated with hazardous materials. Implementing comprehensive risk assessments, providing adequate training, and establishing a strong safety management system are essential steps in mitigating material-related risks. By prioritizing the safety of employees and the environment, LSMEs can achieve sustainable operations while minimizing the potential for accidents, spills, or other adverse incidents.

Management Factors in Large-Scale Manufacturing Enterprises

Management factors are integral to shaping the safety culture and risk management practices within large-scale manufacturing enterprises. These factors encompass the policies, resources, communication channels, and leadership that influence safety performance. Inadequate safety policies, lack of resources, poor communication channels, and ineffective leadership can undermine safety efforts within LSMEs. Recognizing the impact of management factors on safety risk is essential for implementing robust safety management systems and promoting a positive safety culture [48]. Effective safety policies and procedures are the foundation of a strong safety management system. By clearly communicating safety expectations, LSMEs can promote a culture of accountability and ensure that safety is a top priority in all aspects of operations [49]. Allocating sufficient resources for safety programs is crucial for their success. By providing the necessary resources, LSMEs demonstrate their commitment to worker safety and enable employees to carry out their responsibilities in a safe manner [50]. Open and effective communication channels are vital for promoting safety within LSMEs. Encouraging a culture of open communication and actively listening to employees' feedback fosters a sense of trust and empowers individuals to contribute to safety improvement efforts [51]. Leadership plays a critical role in shaping the safety culture within LSMEs. Effective leadership fosters a culture where safety is seen as everyone's responsibility and encourages employees to take ownership of their safety and the safety of their colleagues [52]. Regular safety performance reviews and audits are essential for evaluating the effectiveness of safety management systems within LSMEs. By monitoring safety performance and providing feedback, management can continuously improve safety practices and address potential risks before they escalate [29]. Promoting a positive safety culture is a continuous effort within LSMEs. By fostering a safety culture that values and prioritizes the well-being of employees, LSMEs create an environment where safety becomes an integral part of daily operations [53].

By addressing management factors and implementing robust safety management systems, LSMEs can significantly enhance safety performance and reduce risks. Effective safety policies, allocation of resources, open communication channels, and strong leadership are essential components of a comprehensive safety program. When management demonstrates a genuine commitment to safety, it sets the tone for the entire organization and empowers employees to actively contribute to a safer work environment. By continuously improving safety practices and fostering a positive safety culture, they can protect their workforce and achieve sustainable operations.

Environmental Factors in Large-Scale Manufacturing Enterprises

Environmental factors play a significant role in the operations of large-scale manufacturing enterprises. These factors encompass the conditions and surroundings in which LSMEs operate, including extreme weather conditions, geographical location, and proximity to vulnerable ecosystems. Evaluating the potential risks and impacts of these environmental factors is crucial for developing appropriate contingency plans and ensuring the sustainable operation of LSMEs [54]. Extreme weather conditions can pose various risks to LSMEs. LSMEs should assess the likelihood and impact of these weather events and implement strategies to mitigate their effects. It may include fortifying infrastructure, implementing emergency response plans, or diversifying suppliers to minimize disruptions in the supply chain [55]. LSMEs should also consider the potential impacts of their operations on local communities. LSMEs should engage in open dialogue with the community, address concerns, and implement measures to mitigate negative impacts [56]. Sustainability should be a core consideration for LSMEs in managing environmental factors. By integrating sustainability into their operations, LSMEs can improve their environmental performance and contribute to a more sustainable future [57].

By evaluating and addressing environmental factors, LSMEs can ensure the sustainable operation of their businesses while minimizing risks and impacts on the environment. Implementing strategies to mitigate extreme weather events, managing environmental risks, engaging with local communities, and promoting sustainability are essential for responsible and resilient operations. By adopting a proactive approach to environmental management, LSMEs can not only protect the environment but also enhance their reputation, attract socially conscious customers, and contribute to the long-term success of their businesses.

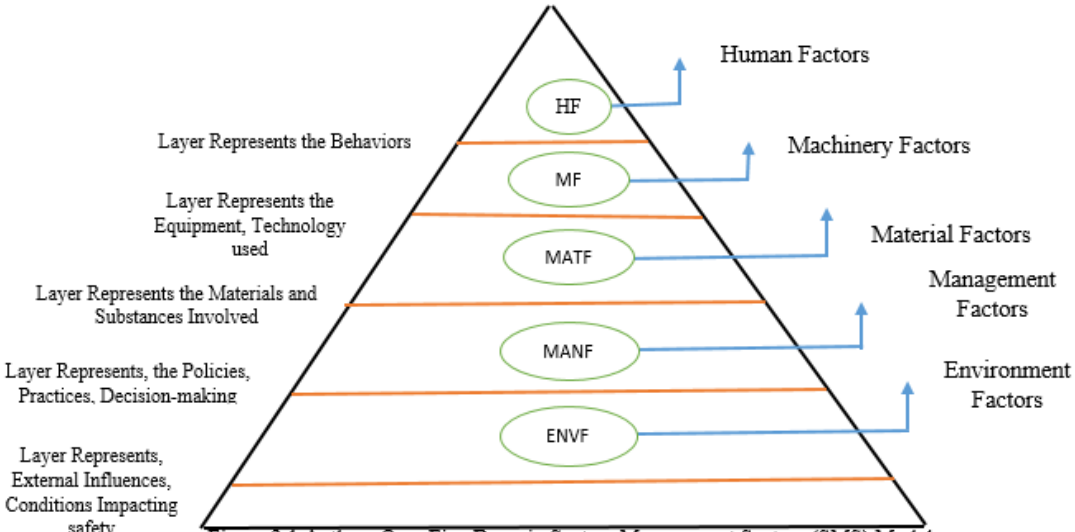


Figure 2.1 Authors Own Five Domain System Management System (SMS) Model

Classifications of Major Safety Risk Factors

The categorization and classification of safety risk factors in LSMEs provide a structured framework for understanding their underlying causes and developing targeted risk management strategies. By organizing risk factors into distinct categories, such as human factors, machinery factors, material factors, management factors, and environmental factors, organizations can prioritize their efforts and allocate resources effectively [58,59].

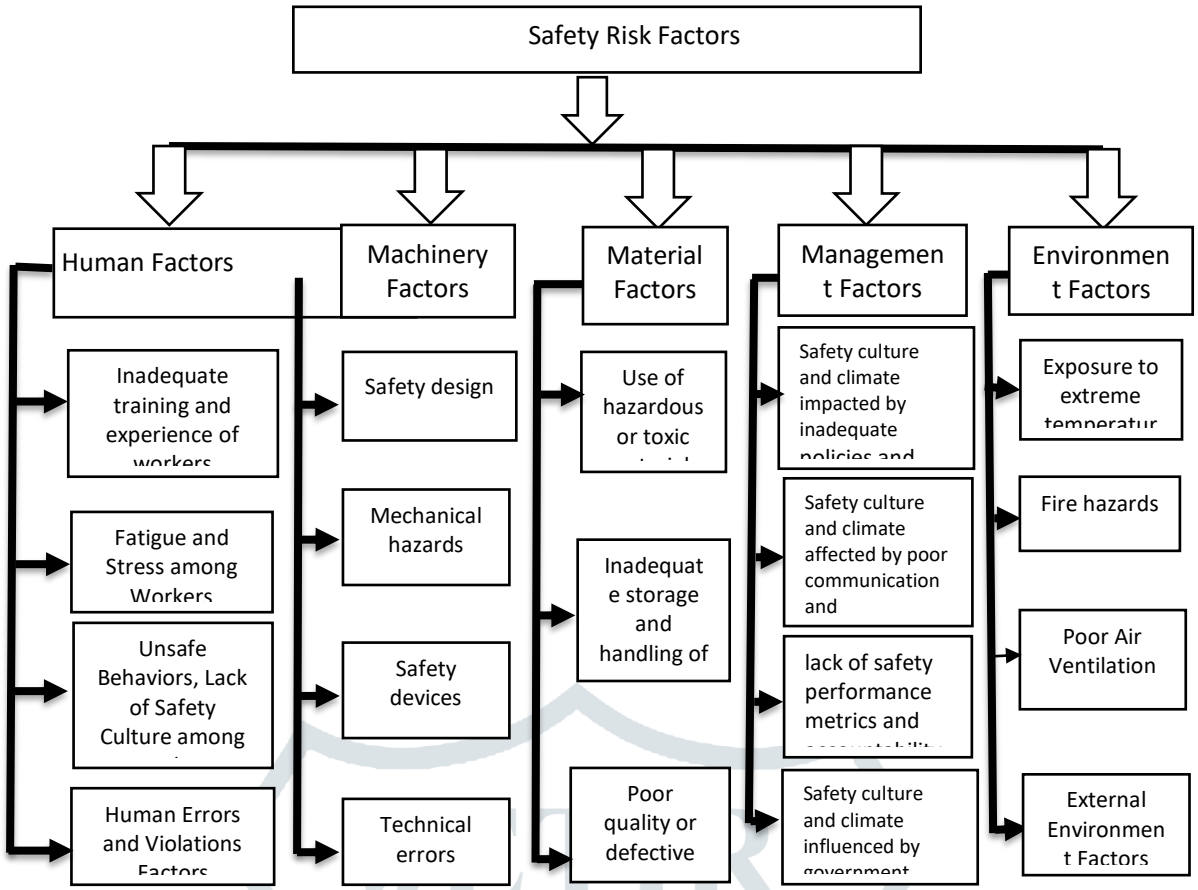


Figure 2-2 Hierarchical Model for Safety Risk Factors

Figure 2.2 illustrate that by building upon the findings of previous literatures, this research aims to contribute to the existing knowledge by proposing an enhanced safety risk assessment approach for LSMEs. This approach integrates various methodologies and considers the specific risk factors identified in the literature to provide a comprehensive understanding of safety risks and develop effective risk management strategies [60,61].

2.3 The Effect of Safety Risk Assessment on Large-Scale Manufacturing Enterprisers

Safety risk assessment in large-scale manufacturing enterprises leads to better decision-making, proactive risk management, regulatory and standard compliance, a stronger safety culture, and continuous improvement. Organizations can effectively optimize safety practices and mitigate risks by identifying the consequences and likelihoods of the risk, using tools such as safety risk matrices, mapping, and ranking, and taking major safety risk factors into consideration [62].

Improved Decision-Making:

Safety risk assessment provides useful information and data about potential risks in large-scale manufacturing operations. Decision-makers can make informed decisions about resource allocation, risk mitigation measures, and strategic planning by analysing the identified major safety risk factors and using tools such as a safety risk matrix and mapping. The analysis assists in identifying critical areas that require immediate attention and enables the development of effective risk management plans [62].

Proactive Risk Management:

The application of safety risk assessment methodologies, such as risk matrix and mapping, promotes proactive risk management. Organizations can identify potential hazards and implement risk-mitigation measures by systematically evaluating and ranking safety risks. This approach allows organizations to be proactive rather than reactive, reducing the likelihood of accidents and incidents while improving overall safety performance [63].

Compliance with Regulations and Standards:

Safety risk assessment, when combined with a thorough understanding of regulations and standards, helps to ensure compliance. Organizations can identify gaps and take necessary actions to meet safety criteria by analysing the identified major safety risk factors

and aligning them with relevant regulations and standards. This helps to create a safe working environment that adheres to industry regulations and standards [64].

Enhanced Safety Culture:

When safety risk assessment is integrated into an organization's safety management system, it helps to foster a more positive safety culture. The analysis of major safety risk factors, as well as the use of risk ranking techniques, highlight the importance of organizational safety. This fosters a common understanding of safety responsibilities, encourages open communication about safety issues, and enables employees to actively participate in risk identification and mitigation. Finally, this leads to a positive safety culture in which safety becomes a core value and is embedded in all aspects of the organization [65].

Continuous Improvement:

Safety risk assessment serves as a foundation for continuous improvement efforts in large-scale manufacturing enterprises. Organizations can track their progress, identify trends, and implement measures to continually improve safety performance by conducting risk assessments on a regular basis and analysing the identified major safety risk factors. The feedback from the safety risk matrix, mapping, and ranking allows organizations to monitor the effectiveness of risk mitigation strategies and make necessary adjustments for further improvement [66]. In summary, the analysis conducted using safety risk assessment methodologies and the identified major safety risk factors contribute to improved decision-making, proactive risk management, compliance with regulations and standards, enhanced safety culture, and continuous improvement in large-scale manufacturing enterprises.

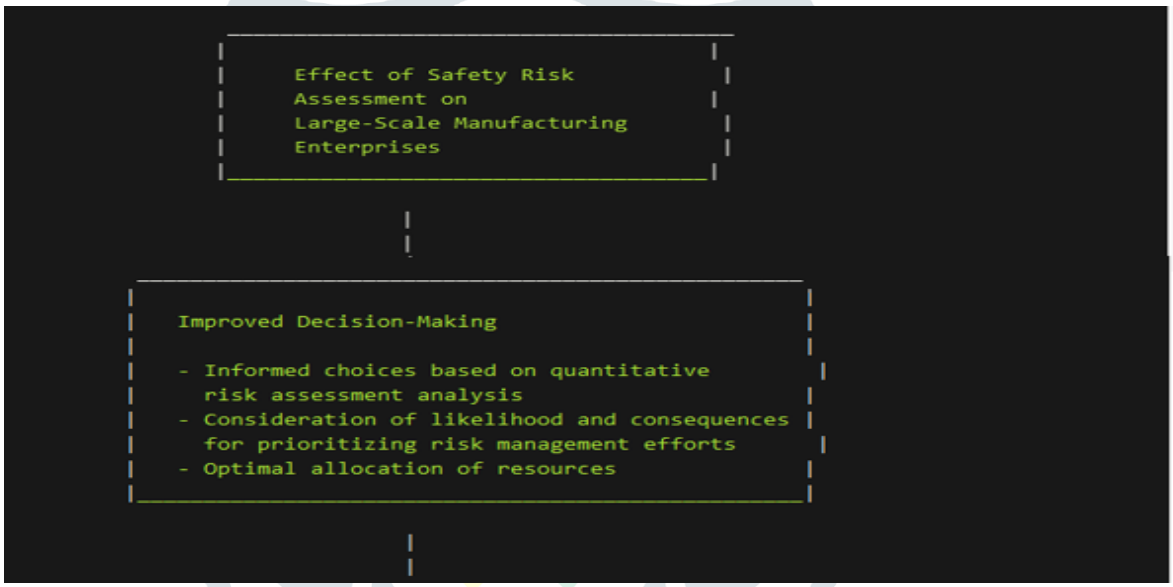
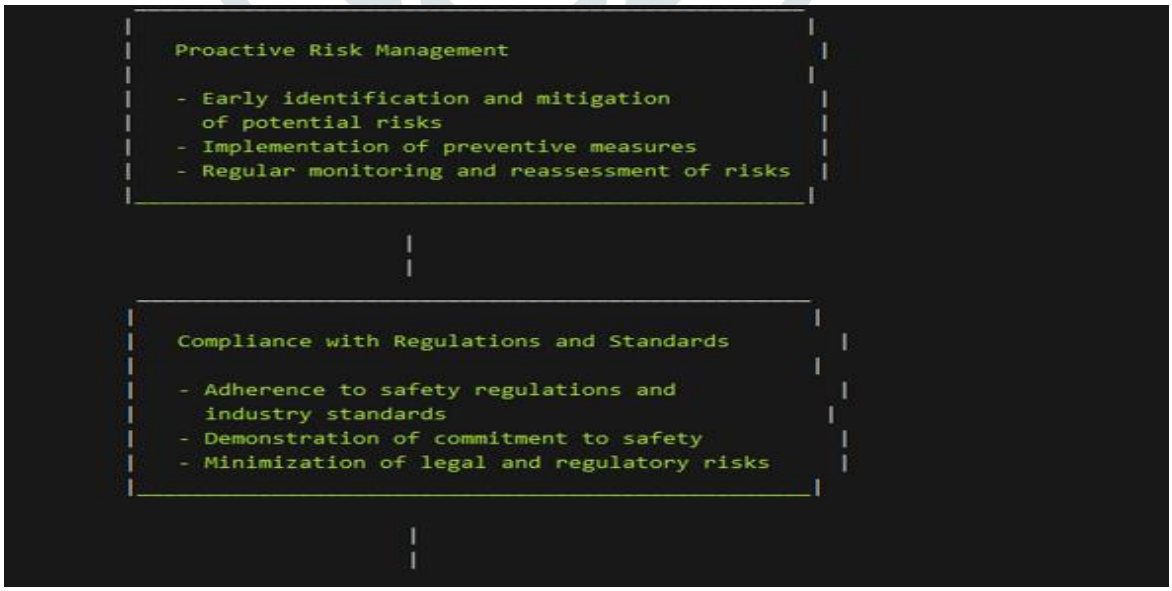
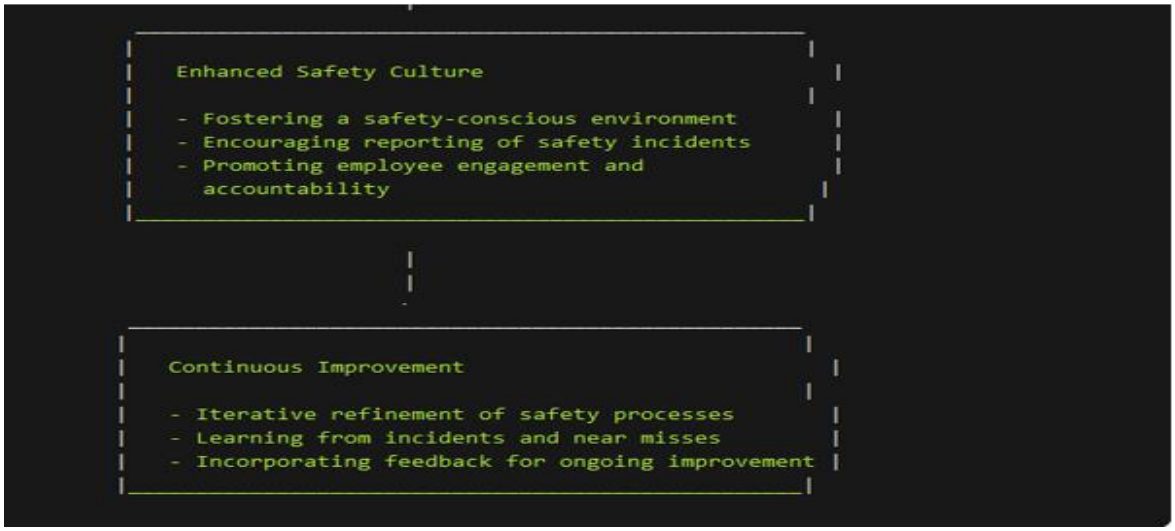


Figure 2.2 The Effect of safety Risk Assessment for large-scale manufacturing enterprises





3. RESEARCH METHODOLOGY

The goal of this study was to investigate the innovating of safety risk assessment activities in three groups of 18 Ethiopia large-scale manufacturing firms [67]. This study was conducted using a qualitative and quantitative research approach and random sampling techniques [68]. The qualitative technique enables the analysis of a phenomenon within its context by employing a descriptive inquiry, such as "What is happening or has happened?" Alternatively, ask an explanation question, such as, "How or why did something happen?" In the study, we use holistic risk assessment methodologies, which are systematic approaches that help identify, analyze, and evaluate potential risks in order to make informed decisions for risk control and mitigation [69]. Some of the commonly used methodologies include:

1. Analytic Hierarchy Process (AHP): AHP is a decision-making tool that allows decision-makers to prioritize and rank multiple criteria in a complex decision-making process. It is widely used in risk management for its ability to handle complex, multi-criteria decision-making problems. AHP involves breaking down a problem into a hierarchy of criteria and alternatives and then assigning weights to each criterion based on their relative importance. It helps in assessing the severity and likelihood of risks and prioritizing them accordingly [70].

2. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method: TOPSIS is a decision-making method that helps identify the best alternative from a set of different options based on multiple criteria. It has been applied in various fields, including risk management, due to its simplicity and effectiveness in dealing with conflicting standards. TOPSIS involves comparing alternatives against ideal and anti-ideal solutions based on different criteria and calculating their relative closeness to these solutions. This method aids in evaluating risks and selecting appropriate risk control measures [71].

These methodologies assist in quantitatively and qualitatively evaluating the severity and likelihood of risks and making informed decisions for risk control and mitigation. By applying these methodologies, manufacturing enterprises can systematically identify and assess risks, allocate resources effectively, and prioritize risk management strategies [72]. Different risk assessment methodologies may be more suitable for different contexts and situations. The choice of methodology depends on factors such as the complexity of the manufacturing processes, the availability of data, and the specific requirements and goals of the risk assessment process [73].

Demographic Data

This suction accomplished the questionnaire data analysis through descriptive analysis, reliability and validity analysis, and exploratory factor analysis (EFA) to explore and validate the risk factors based on experts' and employees" perceptions. However, before the EFA, we established the demographic characteristics of the survey participants described in Table 4-2

Table 3-1 Demographic Characteristics of the Participants

Items	Options	Frequency	Percentage%	Valid(%)	Cumulative %
Employee at ELSME	Yes	359	100.00		
	No	0	0.00		
Gender	Female	139	38.73	38.73	38.73
	Male	220	61.27	61.27	61.27
Age	≤20	8	2.22	2.22	2.22
	21-25	39	10.86	10.86	13.08
	26-30	65	18.13	18.13	31.21
	31-35	78	21.72	21.72	52.93
	36-40	101	28.13	28.13	81.06
	>40	68	18.94	18.94	100
	Total	359	100.0	100	
Education	Bachelor	136	37.88	37.88	37.88
	Masters	116	32.31	32.31	70.19
	PhD	18	5.01	5.01	75.3
	Others	89	24.7	24.7	100
	Total	359	100.0	100	
Experience	1-5	79	22.00	22.00	22.0
	6-10	114	31.75	31.75	53.75
	11-15	120	33.42	33.42	87.19
	>15	46	12.81	12.81	100
	Total	359	100.0	100	
Enterprises Type	Private Owned	131	36.4	36.4	36.4
	State Owned	111	30.20	30.20	66.6
	Multinational	117	33.4	33.4	100
	Total	359	100	100	
Enterprises Categories	Steel processing	60	16.71	16.71	16.71
	Textile, garment	77	21.44	21.44	38.15

* Mean and standard deviation in years provided for age, working experience of the participants
Sources: Researcher survey data construction, 2022

4. RESULT AND DISSCUTIONS

The study's findings and discussion, which combined risk assessment, consequences, and likelihood with ranking, mapping, and a matrix, provided a comprehensive approach to safety risks in large-scale manufacturing enterprises. The risk assessment process made it easier to identify, analyze, and evaluate potential risks, taking into account both their consequences and the likelihood of occurrence. Risks were prioritized and visualized using ranking, mapping, and matrix techniques, allowing for more informed risk control and mitigation decisions. This comprehensive approach enabled a more in-depth understanding of the manufacturing safety landscape, facilitating the development of targeted strategies to improve safety measures and reduce risks.

SAFETY RISK ASSESSMENT

Table 4-1 Risk Assessment Results

No,	Major Safety Risk Factors	Types of Accident	Abb	Likelihood	Consequence	Index	Safety Risk Level
1	Human Factors	Equipment failure	HF1	4	4	16	High Risk
2		Human error:	HF2	5	5	25	High Risk
3		Process failure:	HF3	4	4	16	High Risk
4		Regulatory issues	HF4	4	4	16	High Risk
5		Supply chain disruptions	HF5	3	5	15	High Moderate
6		Environmental accidents	HF6	2	5	10	High Moderate
7	Management Factors	Cyber-attacks:	MANF1	3	4	12	High Moderate
8		Data breaches:	MANF2	3	5	15	High Moderate
9							
10		Phishing scams	MANF3	3	4	12	High Moderate
11		Social engineering	MANF4	2	5	10	High Moderate
12		Insider threats	MANF5	2	4	8	Low Moderate
13	Material Factors	Chemical spills and leaks	MAF1	2	4	8	Low Moderate
14		Fires and explosion	MAF2	2	5	10	High Moderate
15		Chemical exposure	MAF3	3	4	12	High Moderate
16		Confined space accidents	MAF4	1	3	3	Low Risk
17		Chemical reactions	MAF5	1	4	4	Low Risk
18	Machinery Factors	Slips, trips, and falls:	MF1	5	5	25	High Risk
19		Machinery, accidents:	MF2	4	5	20	High Risk
20		Chemical spills and exposure	MF3	4	4	16	High risk
21		Electrical accidents:	MF4	3	4	12	High Moderate
22		Fire and explosions:	MF5	3	5	15	High Moderate
23	Environment Factors	Natural hazards such as viruses, bacteria, and fungi	ENF1	3	4	12	High Moderate
24		Noise-induced hearing loss	ENF2	2	3	6	Low Moderate
25		Musculoskeletal disorders (MSDs):	ENF3	3	3	9	High Moderate
26		Heat stress	ENF4	2	2	4	Low Risk

Source: Researcher Survey Data Constructed in 2023.

Table 4. 1 displays the provided safety risk assessment table, which includes a variety of major safety risk factors in a large-scale manufacturing context, as well as their associated accident types, likelihood, consequence, index, and safety risk level. It provides useful information about potential risks and their respective levels of severity. The analysis results demonstrate that human factors such as human error, equipment failure, and process failure pose significant risks in the manufacturing environment. Regulatory issues and supply chain disruptions add to the high-risk level. Management factors such as cyber-attacks, data breaches, phishing scams, and social engineering pose moderate to high risks. Moderate to high-risk material factors include chemical spills and leaks, fires and explosions, and chemical exposure. Slips, trips, falls, machinery accidents, and chemical spills and exposure all pose significant risks. Natural hazards, noise-induced hearing loss, musculoskeletal disorders (MSDs), and heat stress are examples of moderate to high-risk environmental factors. These findings are consistent with existing literature on safety risks in the manufacturing sector. Studies

frequently highlight the significance of human factors, emphasizing the need for robust training programs, human error reduction strategies, and proactive equipment maintenance to mitigate risks [74]. Regulatory issues and supply chain disruptions have been identified as critical risk factors for operational continuity and overall safety performance [75]. Management factors, including cyber-attacks and data breaches, are well-documented risks in the era of digitalization, necessitating effective cybersecurity measures [76]. Chemical spills, fires, and machinery accidents have all been identified as common safety concerns in manufacturing, highlighting the importance of safety protocols, maintenance practices, and risk control measures [77]. Environmental factors, including natural hazards and occupational health risks such as noise-induced hearing loss and MSDs, have been extensively researched, emphasizing the importance of risk assessment, personal protective equipment, and ergonomic interventions [78]. Overall, the identified safety risk factors and associated risk levels in this study are consistent with previous research, emphasizing the importance of proactive risk management strategies, employee training, regulatory compliance, and investments in safety measures to improve overall safety performance in large-scale manufacturing enterprises.

SAFETY RISK MATRIX RESULT

Table 4-2 The Risk Matrix Determine the Level of Risk and the result

Safety Risk Evaluation Matrix					
Consequence / Likelihood	Insignificant 1	Minor 2	Moderate 3	Severe/Major 4	Catastrophic 5
Certain 5	5				16,22
Likely 4				18,21,23,24	17
Possible 3			14	1,3,9,12,19	2,20,25
Unlikely 2		6, 15	13	7	4,8,26
Rare 1			10	11	

Table 4.2 shows that the safety risk evaluation matrix combines the likelihood and consequence of potential risks, categorizing them into different levels of severity. The matrix allows for a comprehensive assessment of risks, prioritizing them and allocating resources appropriately for risk management. According to the matrix, risks in the "severe/major" and "catastrophic" consequence categories are primarily associated with high likelihood, indicating a significant level of potential harm. Examples include risks 16, 18, 21, 22, 23, and 24. These risks require immediate attention as well as proactive risk control and mitigation measures. The literature confirms the importance of these risks, emphasizing the need for strong safety protocols, hazard identification, and risk reduction strategies. According to studies, major equipment failures, machinery accidents, fires, explosions, and environmental hazards can all have severe and catastrophic consequences. Risks classified as "Moderate," "Minor," or "Insignificant" have varying likelihood values and necessitate careful consideration and risk management strategies. These risks, numbered 1, 2, 3, 4, 7, 8, 9, 12, 13, 14, 15, 17, 19, 20, 25, and 26, may still cause harm, albeit to varying degrees. Existing literature emphasizes the importance of proactive risk assessment and control measures for these risks, which can lead to injuries, process failures, supply chain disruptions, and other safety incidents [75,78].

The risk matrix is a useful tool for decision-making and resource allocation, helping to prioritize risk management efforts. Understanding the potential consequences and likelihood of risks allows organizations to better allocate resources, implement targeted preventive measures, and create strong emergency response plans. It is consistent with the literature, which emphasizes the need for a systematic approach to risk assessment and management in large-scale manufacturing enterprises [76]. In conclusion, the presented safety risk evaluation matrix emphasizes the varying levels of consequence and likelihood associated with potential risks. The matrix's interpretation is consistent with existing literature, emphasizing the importance of proactive risk management strategies and tailored interventions to ensure employee safety and well-being, as well as overall operational continuity in large-scale manufacturing enterprises.

SAFETY RSIK MAPING RESULTS

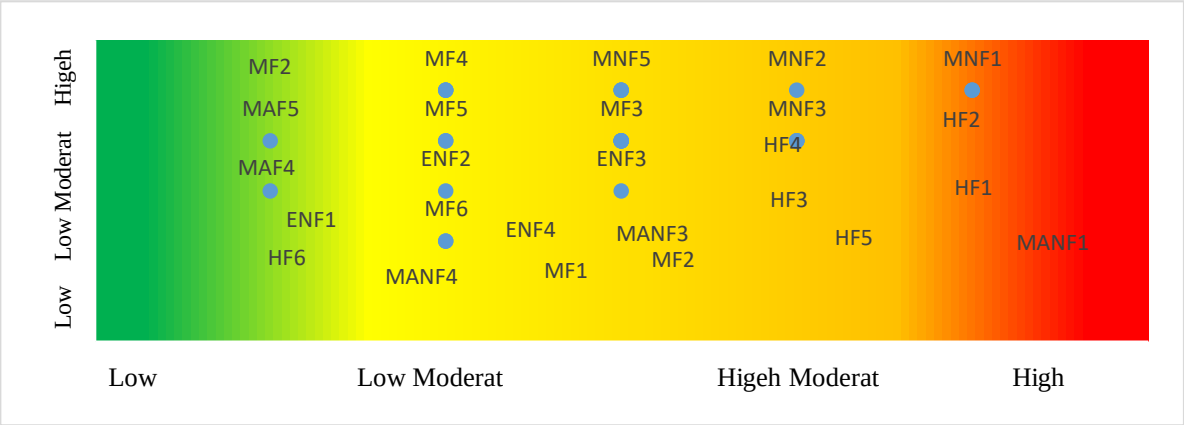


Figure 4-1 Mapping of Safety Risks in Ethiopia Large Scale Manufacturing Enterprises

Figure 4.1 shows that the evaluation of the safety risk mapping results aligns with the previous risk assessment and matrix, providing a comprehensive interpretation of the risks and their corresponding actions. The high-risk category is rightly identified as requiring immediate attention due to the potential for significant harm or damage. The example of MANF1, involving potential cylinder ruptures, highlights the urgency of implementing risk reduction measures to protect workers and prevent production downtime. The recognition of high and moderate risks as notable and requiring timely action is consistent with their classification in the risk matrix. While these risks may not have the severity of high risks, they can still result in substantial impacts. It emphasizes the need for proactive risk management strategies to mitigate their potential consequences. The specific risks identified, such as MF1-MF4, MAF2, MAF3, ENF1, ENF3, MANF4, MANF5, HF5, and HF6, should be addressed promptly to prevent adverse outcomes [76,77].

Regular monitoring and risk control activities are recommended to manage the identified risks effectively. This approach aligns with existing literature, which highlights the importance of continuous monitoring and proactive risk control measures in the manufacturing industry. Implementing these activities allows for early detection of potential risks and facilitates timely interventions to prevent incidents and minimize their impacts.

The evaluation also acknowledges the lower urgency of low to moderate risks and low risks. While these risks may warrant secondary attention, they should still be managed through standard procedures and periodic reviews. It aligns with the risk matrix's classification of moderate and insignificant consequences, which suggests a lower level of attention but still emphasizes the need for appropriate risk management measures [75,76,77].

The integrated approach recommended in the evaluation, which balances the risk priority framework with specific assessments, is aligned with best practices in risk management. Literature supports this approach, emphasizing the importance of considering each risk's unique context and potential consequences when developing risk mitigation strategies.

In conclusion, the evaluation of the safety risk mapping results aligns with the previous risk assessment and matrix, providing a comprehensive interpretation of the risks and their corresponding actions. The analysis emphasizes the need for immediate attention to high-risk and high-moderate risks, regular monitoring and risk control activities, and appropriate management of lower-urgency risks. The recommended integrated approach aligns with existing literature, highlighting the importance of context-specific risk assessments and prioritization in effective risk management strategies in the manufacturing industry.

SAFETY RISK RANKING

Table 4-4 Major Safety Risk SRPI and Rank

Major safety risks	Abb	SRPI	Rank
Machinery Factors	MF	42.24	4
Environmental Factors	ENF	19.05	5
Material Factors	MATF	49.90	3
Management Factors	MANF	56.44	2
Human Factors	HF	57.48	1

The major safety risks identified in the assessment include Machinery Factors (MF), Environmental Factors (ENF), Material Factors (MATF), Management Factors (MANF), and Human Factors (HF). These risks have been ranked based on their Safety Risk Priority Index (SRPI), with Human Factors (HF) having the highest SRPI and Machinery Factors (MF) having the lowest.

The association between these major safety risks and the previous safety risk assessment, safety risk matrix, and safety risk mapping can be discussed as follows:

1. Safety Risk Assessment: The major safety risks identified are consistent with the risks assessed in the previous analysis. The Machinery Factors (MF), Environmental Factors (ENF), Material Factors (MATF), Management Factors (MANF), and Human Factors (HF) were most likely considered in the risk assessment, and their importance was acknowledged. The SRPI ranking provides a quantitative measure for prioritizing these risks while taking into account their potential consequences and likelihood.

2. Safety Risk Matrix: The major safety risks fall into the categories identified in the safety risk matrix. The Machinery Factors (MF), Environmental Factors (ENF), Material Factors (MATF), Management Factors (MANF), and Human Factors (HF) can all be assigned to different parts of the matrix based on their consequences and likelihood. This mapping aids in visualizing risks and developing effective risk management strategies.

3. Safety Risk Mapping: The major safety risks identified in the assessment can be further analysed and mapped using the safety risk mapping method. This mapping provides a comprehensive understanding of the risks, their interdependence, and potential mitigation strategies. By taking into account the consequences and likelihood of each risk, the mapping can help identify the most important areas for risk reduction and control.

Existing literature demonstrates the importance of these major safety risks in the manufacturing industry. Human Factors (HF) play an important role in safety incidents, including human error, fatigue, and inadequate training [79]. Management Factors (MANF) refer to issues such as safety culture, leadership, and organizational practices that influence overall safety performance (Zohar, 2010). Machinery Factors (MF), Material Factors (MATF), and Environmental Factors (ENF) include aspects such as equipment failure, hazardous materials, and environmental hazards, which can cause accidents, injuries, and environmental damage [74,77].

In conclusion, the major safety risks identified in the assessment are consistent with the previous safety risk assessment, safety risk matrix, and mapping. Existing literature supports the significance of these risks, which include Human Factors (HF), Management Factors (MANF), Machinery Factors (MF), Environmental Factors (ENF), and Material Factors (MATF), in contributing to manufacturing safety incidents. The SRPI ranking serves as a foundation for prioritizing these risks and allocating resources towards risk management efforts. Taking into account these major risks and their associated factors is critical for developing effective risk mitigation strategies and promoting a safer work environment.

CONCLUSION

This study aimed to investigate the innovation of safety risk assessment activities in three groups of 18 large-scale manufacturing firms in Ethiopia. A qualitative research approach and random sampling techniques were employed. Holistic risk assessment methodologies, specifically the Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), were used. Data were collected from 359 employees in the 18 manufacturing enterprises. The major safety risks identified in the assessment included Machinery Factors (MF), Environmental Factors (ENF), Material Factors (MATF), Management Factors (MANF), and Human Factors (HF). These risks were ranked based on their Safety Risk Priority Index (SRPI), with Human Factors (HF) having the highest SRPI and Machinery Factors (MF) having the lowest.

The study found that the major safety risks identified align with the risks assessed in the previous analysis, indicating the consistency and validity of the findings. The ranking based on SRPI provides a quantitative measure for prioritizing these risks, considering their potential consequences and likelihood. The alignment between the major safety risks and the safety risk matrix and mapping further validates the results and highlights the importance of visualizing risks and determining appropriate risk management strategies.

The study contributes to the field by introducing innovative safety risk assessment activities in large-scale manufacturing firms in Ethiopia. The utilization of holistic risk assessment methodologies, such as AHP and TOPSIS, enhances the comprehensiveness and effectiveness of the assessment process. The findings shed light on the significance of major safety risks, including Human Factors (HF), Management Factors (MANF), Machinery Factors (MF), Environmental Factors (ENF), and Material Factors (MATF), in the manufacturing industry. The prioritization of these risks based on SRPI provides practical insights for allocating resources and implementing risk management efforts.

Theoretical implications of the study lie in its support for existing literature on the importance of Human Factors (HF) in safety incidents, the influence of Management Factors (MANF) on safety culture, and the impact of Machinery Factors (MF), Material Factors (MATF), and Environmental Factors (ENF) on accidents, injuries, and environmental damage. The study reinforces the need for

proactive risk management strategies to address these major safety risks and promote a safer work environment in large-scale manufacturing firms.

In conclusion, this study presents an innovative approach to safety risk assessment in large-scale manufacturing firms in Ethiopia. The findings emphasize the significance of major safety risks and provide practical insights for risk prioritization and management. The study contributes to the field by introducing holistic risk assessment methodologies and reinforcing existing literature on the importance of various factors in safety incidents. These findings have implications for theory development and highlight the need for proactive risk management practices in the manufacturing industry.

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