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Impact of Supply Chain Traceability on Risk Management and Resilience

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Abstract

Purpose: To investigate how traceability can enhance risk awareness, optimize risk management strategies, and foster resilient supply chain systems in the face of global economic volatility and interconnectedness.

Methodology: An extensive literature review was conducted to examine the relationship between traceability and risk awareness in supply chain management.

Findings: The study revealed that improved traceability significantly enhances supply chain visibility, enabling managers to identify potential vulnerabilities more effectively. Technologies such as AI and machine learning play a crucial role in facilitating timely response and resolution of issues before they escalate. The research also highlighted the importance of leveraging technology to improve traceability, even for small businesses, as it contributes to their competitiveness.

Unique contribution to theory, practice and policy: This study emphasizes the critical role of traceability as an effective tool for risk management and building resilient supply chain systems. It underscores the importance of technological adoption in enhancing traceability across businesses of all sizes, contributing to both theoretical understanding and practical applications in supply chain management.

Keywords: *Supply chain resilience, Supply chain traceability, Supply chain risk management, Technology, Supply chain systems*

1. INTRODUCTION:

Supply chain traceability is becoming an essential tool within the supply chain industry. Increasing consumer awareness and trends require companies to ensure the traceability of their products and services. The concept allows businesses to operate responsibly and provides visibility for the products' consumers [1]. Supply chain traceability systems run through the entire spectrum of the supply chain, from production to distribution. The situation has led to companies tracking and tracing their products through the supply chain system (El et al., 2021). The case also necessitates proper communication, openness, and stakeholder collaboration. The concept is fundamental to global supply chain systems. Factors such as distance and the need to assure consumers of product safety and ethical conduct of the production process [16]. One of the characteristics of the current supply chain system is the disruptions. According to El-Baz, J., & Ruel, S. (2021), the Covid-19 pandemic significantly impacted the supply chain system globally. It was one of the unexpected disruptions to the supply chain system, crippling business and leading to closure. The case necessitated changes regarding risk management in the supply chain networks.

Risk management refers to the ability of a supply chain network to identify risks, conduct risk assessments, and mitigate them to reduce their impact on the system. Risk identification is the initial phase that allows the business to develop screening tools that detect probability and thus help to explore and assess the risk to ascertain its impact on the SCS. Risk assessment helps to determine the effect of the risk on the organization and the interrelationship of risks and trigger events. Risk mitigation and control enact proper measures before the disruptions take place. Sometimes, they help develop contingency plans supporting the business after unprecedented events, improving resilience. Supply chain resilience is an essential concept given the need for companies to stay resilient, survive disruptions, and ensure growth in turbulent times. Supply chain resilience refers to the ability of the supply chain network to prepare and adapt to the disruptions that occur. They can adjust and continue functioning amid the disruptions (El-Baz & Ruel, 2021). Supply chain traceability is the foundation for risk management and resilience within the supply network and thus needs proper analysis to ensure its impact on the overall performance.

Despite the growing recognition of traceability within supply chain networks, there is a gap in understanding how traceability translates to risk management and overall resilience. The research aims to delve into the issue further and analyze the mechanisms by which traceability affects risk awareness, management, and the organization's resilience.

The primary objectives of the study include:

1. To examine how improved traceability enhances risk awareness in supply chains.
2. To analyze the relationship between traceability and the effectiveness of risk management strategies.
3. To evaluate the impact of traceability on supply chain resilience

4. To identify best practices in leveraging traceability to build more resilient supply chains.

Addressing the objectives will play an essential role in research, contributing to the theoretical understanding of the concept within supply chain networks. It will also provide direction to industry professionals, allowing them to find evidence-based methods of translating traceability into creating a resilient supply chain network that can withstand disruptions and remain profitable.

2. LITERATURE REVIEW

2.1 Supply Chain Traceability: In recent years, supply chain traceability has become a critical component that has given companies an edge. The increasing regulatory requirements alongside the consumer demand in the evolution of technology necessitate traceability efforts by the companies. Ref [4] defines supply chain traceability as the movement of products and goods within the specific supply chain network from production to distribution. The definition includes essential functions such as tracking and also tracing the goods. Different industries utilize traceability systems to track their goods and ensure consumer transparency. The food industry and pharmaceutical companies pioneered the need for traceability to guarantee product quality across different markets [11]. It helps in quality assurance in the food industry, given the need to meet certain specifications in the global food trade [4]. Some of the benefits of traceability include the ability to ensure the safety of the products, quality assurance, risk management, and supply chain optimization. Technology is changing how companies enforce travel measures by optimizing and automating the system. An example is the merging blockchain technology, which helps record keeping using an immutable system, while other technologies, such as the Internet of Things (IoT), help in real-time tracking [15].

2.2 Risk Management in Supply Chain: Risk management makes the supply chain system resilient to disruptions and varying market conditions. After the pandemic, supply chain risk management (SCRM) has taken a different trajectory, as most companies have made it the focal point of their business, ensuring that they manage the risk to prevent business closure in disruptions [5]. Risk does not only include external factors like the recent pandemic but also other internal systems on the supply chain, such as proper inventory management systems and quality control [11]. Supply chain traceability is essential in risk management as it identifies vulnerabilities that facilitate risk management. Supply chain managers must first identify the risks, assess, mitigate, and monitor them to ensure they are not problematic to the system. Traditionally, the role of supply chain risk management was reactive. Given the disruptions that took place, most companies could remain operational after the disruptions took place. However, different factors make risk management a priority for any business that wants sustainable growth. There are very few monopolistic industries, and given the many players in the market, proactive risk management is critical for companies to maintain their place in the marketplace. Effective risk management helps to build upon Supply chain resilience with a holistic view of the supply chain system and global

market trends [1]. Systematic review highlighted data analytics as the key to helping companies stay informed and predict risk through machine learning technologies [9]. Thus, Technology is at the forefront of supply chain management functions, including risk management and traceability.

2.3 Supply Chain Resilience: Supply chain resilience refers to the ability of the organizations to prepare, respond effectively, and recover from any disruptions affecting the business. The element ensures business continuity at the desired level by controlling the function and business structure. Resilience has become a key predictor of success today, given the impact of the pandemic on businesses, as most could not recover. Some essential factors contributing to supply chain resilience include visibility through proper treatability systems, business flexibility to adjust to changing needs, collaboration with other stakeholders to ensure risk spread, and building solid resources to counteract the effect of disruptions [10]. Technology is a crucial tool that most companies leverage to ensure resilience. It helps by ensuring collaboration, for example, within the supply chain network. Managers can track goods and communicate in real-time with the stakeholders, which helps to ensure timely responses to issues. The team can develop effective strategies to minimize risk and remain relevant and operational afterward [5]. They had overseas production factors that were affected during the pandemic, limiting the supply sources. The case led to business closure, which affected their resilience. For the companies that were able to re-strategize on time, they remained operational after the pandemic [5]. Apart from technology, other vital precedents in building a robust supply chain include system thinking and awareness of the complex elements operating within the supply chain network.

2.4 Research Gap: Most studies have individually examined traceability, risk management, and resilience. However, very few have looked into the relationship between the different elements. Traceability systems are vital in supporting risk management, which helps companies respond timely to quality product issues, ensuring resilience. Existing literature focuses on the isolated parts of the traceability function, limiting comprehensive understanding of the concept and its impact. There is minimal research on how companies can leverage traceability using a systematic methodology to build resilience [1]. The paper's primary purpose is to explore the concept of supply chain traceability in depth to build an understanding of its impact on risk management and resilience. The focus is on the recovery abilities and responses to ensure that companies have a framework to help them build resilient supply chain systems. The study is relevant given that it offers practical recommendations to assist businesses in effectively navigating the risks and disruptions.

3. METHODOLOGY:

A systematic review was used to gather data regarding the impact of supply chain traceability on risk management and resilience. The systematic literature review (SLR) method was beneficial for eradicating bias [2]. It helped to review the articles and ensure they were relevant to understanding

the topic. The method helped to analyze different literature regarding the topic to obtain valuable insights that are important for companies trying to ensure supply chain resilience.

The initial stage was defining the purpose of the study, and it has been stated that there are four primary goals. These include determining the impact of improved traceability on risk awareness and analyzing the relationship between traceability and risk management strategies. The other goal is to evaluate the impact of traceability on resilience and the best practices for leveraging traceability to build resilient supply chain networks.

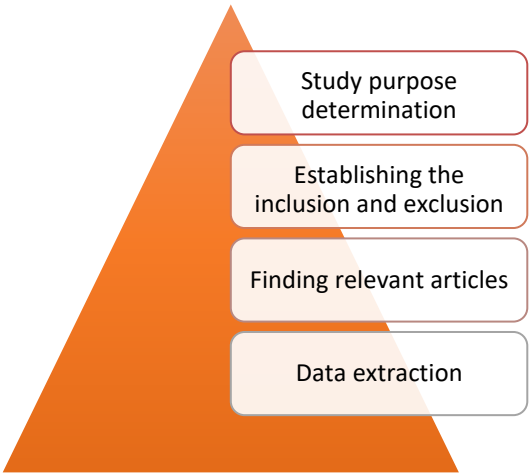

Figure 1: Study Design Process

Step 2 involved developing the inclusion and exclusion criteria as shown in Fig. 1. The goal is to ensure only relevant sources are used. The different criteria used include assessing the articles' sources. Scopus and other reputable databases such as EBSCOhost, Science Direct, and IEEE Xplore helped obtain relevant sources. The strategy helped to widen the coverage and improve the research sources. Determining the keywords was the other step that helped to consider the terms that could be used to refer to traceability. Different keywords referred to traceability, resilience, supply chain resilience, risk management, risk mitigation, transparency, recall, visibility, and supply chain. Assessing the journal quality was also an essential part of the criteria that helped to include published studies among the high-ranking journals in the business and supply chain niches.

The third step was to identify potential literature using the criteria created. The search retrieved 654 sources and 223 peer-reviewed articles on the subject. Only peer-reviewed articles were selected from the research pool. The other filter used is time; only current sources within the last five years were included. Reviewers checked the remaining articles to determine relevance and alignment with the research topic. Those that did not meet the criteria based on keywords were removed. The reviewers screen the articles based on the abstract and the full-text review to ensure they fit the criteria and provide information that would contribute to answering the research questions. Two independent reviewers took part in the review process, as having more than one reviewer helps reduce bias and ensure the inclusion of quality papers [2].

The fourth stage was data extraction, which utilized the thematic content analysis method. It grouped the data into different categories, each addressing the research questions. The strategy offered insight into the trends and patterns of each source as they contributed to answering the research questions [17]. The findings were then analyzed and presented to answer the research questions.

4. OVERVIEW OF THE CURRENT LITERATURE ON SUPPLY CHAIN TRACEABILITY AND THE IMPACT ON RISK MANAGEMENT AND RESILIENCE

This section outlines the findings from the literature review to explain the impact of supply chain traceability on risk management and supply chain resilience. The articles used have a publication date of between 2018 and 2024 and are thus current. A total of 16 sources were obtained. Most papers were from the US, Europe, and other smaller countries, which accounted for the few articles.

4.1 The Role of Supply Chain Visibility in Risk Awareness: Supply chain traceability allows supply chain managers to track the origin, movement, and goods of products, information, or materials across the supply chain network [14]. Different methods help ensure supply chain traceability, such as using RFID, GPS, and blockchain technologies. There is a significant difference between supply chain traceability and visibility. While traceability focuses on tracking goods and services, visibility is a concept that focuses on a broader supply chain context, allowing for greater collaboration and information sharing [14]. The prerequisite to supply chain visibility is tracing the goods and the services. Traceability allows companies to capture specific data regarding the supply chain. Some of them include information on goods movement. Certifications and the location of the different facilities. Such data is essential in monitoring the supply chain and ensuring that companies identify and mitigate risks and vulnerabilities.

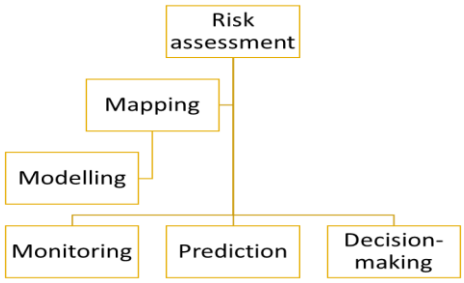

Figure 2: Supply chain traceability process

The traceability function lays the foundation with up-to-date data, which the supply chain manager can use to ensure visibility. Visibility focuses on a broader scope than traceability. It looks at the supply chain system to help identify challenges and vulnerabilities and enhance operational efficiency to ensure the business is resilient and optimal. One of the ways that traceability

contributes to visibility is through the real-time tracking of data. When companies utilize tracking technologies like IoT, the supply chain manager can track real-time data across the network [1]. The company can improve visibility by understanding the inventory movements, shipment status, and product location. Such data offers a picture of the supply chain dynamics, which is vital to the managers to allow them to make predictions, respond when issues arise, and make proactive changes to ensure smooth activities across the chain.

The other impact of improved traceability is that it helps in data aggregation and decision-making. It provides data that, when aggregated, helps analyze and identify trends and patterns across the supply chain. Such data can potentially improve strategies to optimize the supply chain performance [10]. The supply chain manager can make improvements on identified vulnerabilities using the data. Therefore, traceability helps provide credible data, which translates to valuable information that improves the quality of decision-making. The other impact, as Fig. 2 outlines, is the supply chain mapping function, as improved visibility allows the business to create visual representations of the supply chain. It allows the stakeholders to understand better the relationships between the suppliers, producers, distributors, and intermediaries. A perfect example is a company optimizing its routes in the supply chain due to improved visibility, which is vital in streamlining the process to ensure efficient resource use and profitability.

4.2 The Relationship between Traceability and the Effectiveness of Risk Management Strategies

Traceability significantly affects and determines risk management strategies and their success. There are many ways to measure the relationship between the two and their impact, including risk reduction rates, mean time to detect, mean time to resolve, and the supply chain visibility index. Supply chain traceability is directly related to effective risk management strategies within the food industry [8]. The analysis suggests that traceability offers a competitive advantage over other food companies, allowing businesses to respond to incidents and scandals more quickly, ensuring resilience. One way that improved traceability benefits the business is through quality decision-making. Effective traceability systems provide businesses with data that gives them visibility into the supply chain system as a whole. Such insights allow the business to conduct traceback investigations to understand why inevitable mistakes occurred and learn from them. In the food industry, for example, improved visibility helps the companies pinpoint the contamination sources as the foods move from one supply chain point to the next [4]. It, therefore, allows the business to reduce foodborne diseases as they can quickly do product recalls, which minimizes the impact of such activities on the population's health.

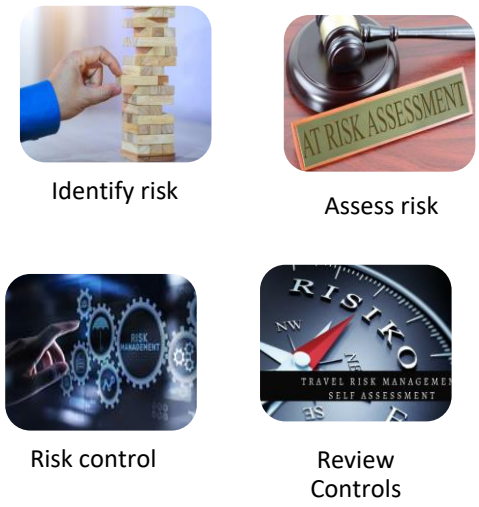

Figure 3: Risk management process

Specific industries benefit significantly from improved decision-making through visibility, such as the pharmaceutical, medical, and food industries. The data helps prevent deaths, loss of life, and severe outcomes affecting the population's lives and health. 2017, for example, Equifax experienced a data breach within its system that led to the loss of compromising and sensitive information of over 162 million British and US citizens [12]. One of the causes of the incident was poor visibility into the system to allow for real-time data tracking. There was a delay in the detection, which allowed the attackers to maintain unauthorized access to the system for a long time. Poor monitoring practices also affected the ability to detect anomalies leading to the incident. The lack of traceability and visibility thus affected the company and led to poor decisions that cost the business financial loss, consumer trust, and identity theft of client data. Therefore, the data that improves the quality of decision-making improves the efficacy of the interventions enacted, reduces the risk, and reduces the mean time to detect and the mean time to resolve issues.

The other role of improved traceability in risk management is promoting proactiveness. The business can detect potential issues within the system early, allowing for easy recovery. One of the industries that benefits from using a sophisticated traceability system is the pharmaceuticals. Pharmaceutical companies focusing on drug manufacturing have a sophisticated supply chain traceability system with features allowing real-time monitoring of different parameters such as humidity and temperature [7]. The system works throughout the production process until the distribution for quality control purposes. By analyzing the data, the companies can detect issues before they become problematic, thus helping in risk management. If the system detects a deviation from the suitable temperature, the team takes measures to address that, which ensures that the issue only affects a small batch of the final products. In that sense, traceability correlates with effective risk management, given the ability to identify and address anomalies promptly. The strategy is also effective given that it saves the organization from significant losses arising from mass-

producing poor-quality drugs, the loss in investments, the public PR from supplying ineffective medications, and the time it takes to recover from the significant losses [11]. As Fig. 3 shows, traceability triggers the risk management process that facilitates proactive response to issues, reduces the risk level, mean time to detect, and the mean time to resolve, ensuring transparency and visibility across the supply chain (El-Baz & Ruel, 2021). The strategy makes the decisions effective, given that they arise from real-time data and analysis of past trends and future actions.

4.3 The Impact of Traceability on Supply Chain Resilience: Traceability is a prerequisite to building a sustainable business and ensuring resilience. Transparency helps manage crises by containing risk and allowing the organization to recover quickly [6]. It does so in many ways; one is through the improved visibility that allows for system monitoring. It helps to understand who made the items, the raw materials used, and the stakeholders who have helped contribute to the product manufacturing process until they reached the consumers. Such data allows the supply chain manager to pinpoint issues once they take place. Such data is helpful in crisis management as the manager knows all the stakeholders and their role in facilitating the product movement. The improved visibility pinpoints the source of the issue, making it easy to resolve issues in time before they cause a public relations scandal. It also minimizes the impact of the risk, given that the supply chain manager resolves the issue on time. The data informs the decision-making process, making it possible to resolve issues [14]. Regarding manufacturing industries and food processing, product recall issues occur frequently due to the lack of visibility in the supply chain systems. When such incidences occur, it is hard to resolve them without understanding the supply chain system and the movement of goods across the chain. It also reduces accountability in that sense.

A study done in Sub-Saharan Africa showed that transparency is the key that enables small-scale businesses to remain resilient amid disruptions in the business environment [13]. Even though the businesses are small-scale, coming together allows the individuals to pool resources and ensure they acquire the right technologies. Traceability has become a necessity and not a luxury business tool, allowing business persons to have visibility of the supply chain network, which helps them make business decisions. It allows them to remain resilient due to the ability to forecast and manage the crisis confidently due to available data. Transparency increased African resilience by ensuring businesses adhere to the agreed-upon standards and safety precautions [13]. They have the proof to show that all stakeholders across the supply chain, from the farmers to the distributors, complied with the required standards. This aspect ensures that they remain competitive in the global markets and thus build the resilience of their businesses. The visibility allowed the stakeholders to detect non-conformance issues early on, facilitating the withdrawal of the affected products from the supply chain. Such strategies ensure the timely resolution of issues, which protects the businesses from negative publicity or performance that could affect their business opportunities. Indirectly, traceability helps to plan for the supply and demand needs of the stakeholders due to the available historical data. Companies then allocate resources effectively and thus become more competent in fulfilling their roles economically, preventing loss that can affect

business continuity [4]. It also indirectly fosters collaboration among the different stakeholders, making it possible to coordinate activities and resolve issues promptly when they take place. Businesses can, therefore, create a risk management culture as they have a traceability system in place to help in product inspection, verification, and movement. The supply chain systems become resilient and gain a competitive advantage through timely response to crises and the ability to recover from crises.

5. BEST PRACTICES IN LEVERAGING TRACEABILITY TO BUILD MORE RESILIENT SUPPLY CHAINS

Understanding how to leverage traceability best helps companies build more resilient supply chain systems. Technology is a company's primary tool for leveraging traceability to ensure resilient supply chain systems. There is a growing trend towards incorporating technological tools in the supply chain systems, given the benefits businesses accrue from using them [18]. As Fig. 4 shows, the use of different technologies is growing, starting with blockchain technology, IoT, Artificial intelligence, serialization of standards, and mobile applications. One of the best practices is ensuring End-to-End Visibility and Transparency [19]. The concept refers to the ability of the supply chain system to track products from production to the end consumer. The strategy is critical as it helps identify and address bottlenecks before they become problematic. Ref [3] recommends leveraging technology to ensure end-to-end visibility across the supply chain system. One of the challenges among small business owners is acquiring technologies. A study in Sub-Saharan Africa demonstrated the power of collaboration among small businesses in acquiring technologies that promote traceability [13]. Companies can thus find innovative ways of acquiring the technologies to help them build resilient businesses.

Internet of Things technology can help foster intelligence, networking, connectivity, visibility, and transparency. It ensures real-time data tracking and monitoring via the IoT sensors placed in the products and other systems, such as containers. The strategy ensures that inventory management optimizes resources by reducing stockouts and overstocking. The business identifies issues and proactively solves them due to the ability to harness available data using IoT technologies. There is also the predictive maintenance feature, allowing the businesses to decrease issues with equipment failure and allowing for proactive strategies to ensure the equipment is in good condition and operational [18]. Through improved end-to-end visibility, the business can foresee incidences and thus take action to address them, ensuring supply chain resilience.

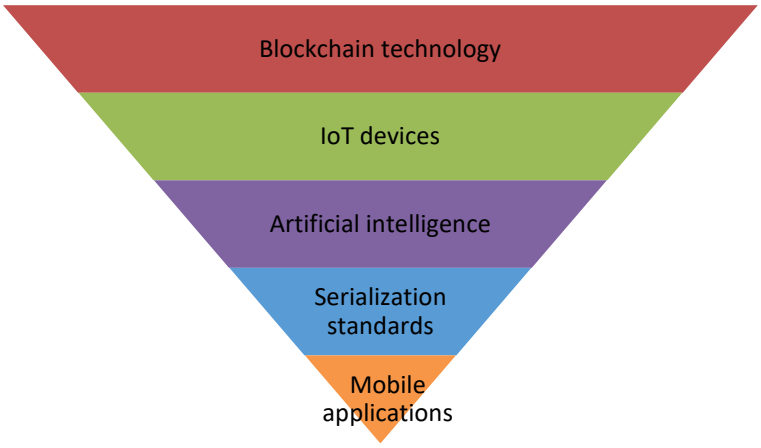

Figure 4: Increased integration of technology in supply chain management

Blockchain technology creates a decentralized and transparent system to ensure safety, tamper-proof proof, and immutable record keeping, which helps keep and maintain accurate records [15]. The supply chain manager can verify goods, detect counterfeits, automate the process, and thus ensure proper risk management and incidence responses, which is crucial in building a robust supply chain system. AI can also help take advantage of the data collected through blockchain systems through machine learning to make predictions that help businesses prepare in advance. The business can develop proactive strategies that improve its resilience in mitigating risk and reducing its impact on the organizational bottom line. Sterilization of standards is another technology becoming prevalent due to the ability to facilitate seamless data exchange across the supply chain system through devices and systems [18]. The increased interoperability increases visibility, reducing errors and ensuring proper monitoring of products across the supply chain. The other tool to leverage in increasing transparency is mobile application use. The stakeholders have access to data and insights as they take place within the supply chain system. The applications are convenient and accessible, making monitoring and tracking supply chain data easy. It also improved collaboration among stakeholders, making it easy to resolve issues promptly.

6. CONCLUSION

In summary, research findings show that supply chain traceability is an essential concept all supply chain systems must have. The function is especially critical today, given the changing market demands, demographic preferences, and the emergence of new technologies that could help companies gain a competitive advantage over others. The increased openness of the global market exposes companies and businesses to international competitors, necessitating the need to ensure visibility and contribute to the resilience of the supply chain systems. Supply chain managers can anticipate needs and enact effective risk management strategies by improving visibility by having suitable structures to track the movement of goods and services. The findings show that improved visibility facilitates risk identification and supports faster and more coordinated responses to disruptions. The effect of improved visibility, effective risk management, and forecasting is

improved resilience as companies recover faster from disruptions, making them competitive in a global market.

The study also revealed the best practices for using technology to leverage traceability to ensure supply chain resilience. Technologies are becoming prevalent today, and the case study done in sub-Saharan Africa showed how small businesses are coming together to leverage resources to acquire technologies that facilitate traceability. The element positions the businesses high in the global supply chain due to the ability to ensure quality, safety, and products that meet the specified standards, all due to the traceability strategies in place. Some of the mentioned technologies include blockchain technology, artificial intelligence, mobile applications, the Internet of Things, and serialization standards. Companies can utilize the tools to leverage them to ensure improved visibility across the supply chain, which keeps them updated on the real-time movement of goods, facilitating faster response and recovery from incidences. The implications of the findings are to encourage companies to leverage the above technological tools and follow the guidelines to ensure visibility in the businesses and build resilient businesses amid today's unstable business environment.

7. RECOMMENDATIONS

Based on this study's findings, organizations should prioritize investment in emerging technologies such as blockchain, IoT, and AI while developing clear implementation roadmaps aligned with their traceability goals and risk management strategies. Companies should establish standardized procedures for data collection and analysis, focusing on end-to-end visibility solutions across their supply chain networks. Training programs and capacity building initiatives are essential to enhance staff competency in using traceability technologies and data analytics. Organizations should foster stronger relationships with suppliers and partners to ensure seamless information sharing, while also establishing clear communication channels for risk reporting and incident response. For sustainable implementation, companies should regularly review and update their risk management protocols based on traceability insights, while maintaining compliance with international standards and regulations.

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