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Supply Chain Risk Analysis Using Failure Mode and Effect Analysis (FMEA)

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Abstract: *Supply chain complexity and uncertainty have increased significantly due to globalization, technological interdependence, and recent global disruptions. These conditions expose organizations to various risks that may negatively affect operational performance, resilience, and competitiveness. This study aims to analyze supply chain risks using Failure Mode and Effect Analysis (FMEA) as a systematic and structured risk assessment tool. A qualitative–quantitative research design was employed by identifying potential failure modes across supply chain processes, evaluating their severity, occurrence, and detectability, and calculating the Risk Priority Number (RPN). The analysis demonstrates that FMEA is effective in prioritizing critical risks and supporting decision-making for mitigation strategies. The findings indicate that supplier-related risks, process disruptions, and external shocks such as pandemics and geopolitical conflicts represent the most critical risk categories. Comparative analysis with previous studies confirms that modified and integrated FMEA approaches enhance risk visibility and mitigation effectiveness. This study contributes to the supply chain risk management literature by synthesizing empirical evidence from various industrial contexts and providing a structured framework applicable to both manufacturing and service industries. Practical implications include improved risk prioritization, enhanced supplier evaluation, and stronger organizational resilience.*

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INTRODUCTION

Supply chain systems have become increasingly complex as organizations expand their operations across national and international boundaries. Global sourcing strategies, multi-tier supplier networks, and high levels of interdependence among supply chain actors have significantly increased exposure to uncertainty and disruption. In this context, supply chain risk is no longer an exceptional condition but an inherent characteristic of modern operations. Empirical evidence shows that disruptions in supply chains can result in production stoppages, cost escalation, loss of customer trust, and long-term competitiveness decline, particularly in manufacturing and process-based industries (Sangode; Cano-Olivos et al.). Therefore, systematic and proactive supply chain risk management has become a strategic priority for organizations.

Supply chain risks originate from multiple sources, including suppliers, internal processes, logistics systems, information flows, and external environments. Supplier-related risks, such as delivery delays, quality failures, and dependency on limited sources, are consistently reported as major contributors to operational instability (Li & Zeng; Zhang & Sharifnia). Internally, process failures caused by equipment breakdowns, human error, or inadequate coordination can propagate rapidly across interconnected supply chain stages. These risks are further amplified by external factors such as

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regulatory changes, natural disasters, pandemics, and geopolitical conflicts, which are often characterized by high severity and low probability (Bani-Irshid et al.; Goel et al.).

Traditional supply chain risk management approaches often rely on reactive measures implemented after disruptions occur. Such approaches limit organizations' ability to anticipate failures and reduce their potential impacts. As a result, there has been a growing emphasis on proactive risk identification and prioritization tools that support early intervention. Failure Mode and Effect Analysis (FMEA) has emerged as one of the most widely applied methods in this regard. Originally developed for quality and reliability engineering, FMEA has been adapted extensively to assess risks in supply chain contexts due to its structured and systematic nature (Li & Zeng; Liu & Chen).

FMEA enables organizations to identify potential failure modes within supply chain processes, evaluate their effects, and prioritize risks based on severity, occurrence, and detection criteria. This structured assessment provides clear guidance for allocating managerial attention and resources toward the most critical risks. Numerous empirical studies demonstrate the applicability of FMEA across diverse industrial settings, including heavy industry, cement manufacturing, biofuel supply chains, food supply chains, and retail distribution systems (Dendera-Gruszka & Kulińska; Wachyudi et al.; Sangode; Zhang & Sharifnia). These studies consistently report that FMEA improves risk visibility and supports more systematic mitigation planning.

Despite its strengths, conventional FMEA has been criticized for limitations related to subjectivity, linear risk prioritization, and insufficient consideration of interdependencies among risk factors. In response, recent studies have proposed modified and integrated FMEA approaches that combine FMEA with multi-criteria decision-making techniques. Integrations with methods such as the Analytic Hierarchy Process, PROMETHEE, fuzzy VIKOR, and interpretive structural modeling have been shown to enhance the robustness and consistency of risk assessments (Jafari & Lohrasbi; Rathore et al.; Altubaishe & Desai). These hybrid models allow for more nuanced evaluation of complex supply chain risk structures.

The relevance of FMEA-based supply chain risk analysis has been further reinforced by recent global disruptions. The COVID-19 pandemic exposed structural vulnerabilities in global supply chains, including overreliance on specific regions, lack of flexibility, and limited visibility across tiers. Empirical studies applying FMEA during the pandemic period demonstrate its effectiveness in identifying high-severity risks and supporting strategic mitigation under extreme uncertainty (Bani-Irshid et al.). Similarly, research addressing geopolitical conflicts highlights the importance of prioritizing low-probability but high-impact risks to enhance supply chain resilience (Goel et al.).

Although the existing literature provides extensive evidence of FMEA applications in supply chain risk management, several gaps remain. Many studies focus on single-industry or single-case analyses, which limits the generalizability of findings and the development of comprehensive strategic insights. In addition, empirical results are often reported in isolation, without systematic synthesis across sectors and risk categories (Henni et al.; Affriadi Anggara). Consequently, there is a need for integrative analysis that consolidates empirical evidence and clarifies the strategic value of FMEA for supply chain risk management.

Based on these considerations, this study aims to analyze supply chain risks using Failure Mode and Effect Analysis by synthesizing empirical findings from diverse industrial contexts. The study seeks to demonstrate how FMEA supports systematic risk identification, prioritization, and mitigation across supply chain stages. The contribution of this research lies in strengthening the conceptual and empirical foundation of FMEA-based supply chain risk analysis and providing a structured reference for practitioners and researchers seeking to enhance supply chain resilience.

RESEARCH METHOD

Research Design

This study employed a qualitative–quantitative research design based on systematic analysis and synthesis of empirical studies applying Failure Mode and Effect Analysis (FMEA) in supply chain risk management. The design was selected to allow structured identification, comparison, and interpretation of risk categories, failure modes, and mitigation priorities across different industrial contexts without altering the original empirical findings reported in prior studies.

Data Sources and Selection Criteria

The data used in this study were derived exclusively from peer-reviewed journal articles, conference proceedings, and scholarly book chapters that explicitly applied FMEA or modified FMEA approaches in supply chain risk analysis. Only sources included in the article's reference list were considered. The selection criteria required that each study clearly describe supply chain processes, identify failure modes, and report risk prioritization using severity, occurrence, and detection dimensions or their validated modifications. This approach ensured methodological consistency and analytical comparability across studies.

Data Collection Procedure

Data collection was conducted through structured document analysis. For each selected study, relevant information was extracted, including supply chain context, identified risk sources, failure modes, assessment criteria, and mitigation focus. The extraction process followed a standardized template to maintain consistency and reduce interpretive bias. No primary data collection, surveys, experiments, or simulations were conducted in this study.

Data Analysis Technique

The analysis followed the core principles of Failure Mode and Effect Analysis. Identified failure modes were examined based on their reported severity, occurrence, and detection characteristics. Where studies applied modified or integrated FMEA models, such as combinations with multi-criteria decision-making techniques, the analysis focused on how these modifications influenced risk prioritization outcomes. Risk Priority Numbers and equivalent prioritization indicators were compared across studies to identify dominant risk categories and recurring patterns.

Validity and Reliability Considerations

To enhance analytical rigor, triangulation was achieved by comparing findings across multiple industries and methodological approaches within the existing literature. Consistency of risk prioritization results was examined to assess reliability, while alignment with established FMEA frameworks supported construct validity. By relying solely on documented empirical evidence, the study maintained transparency and replicability.

RESULTS AND DISCUSSION

Overview of Identified Supply Chain Risks

The synthesis of empirical studies indicates that supply chain risks assessed using FMEA consistently cluster into three main categories: supplier-related risks, internal process risks, and external environmental risks. Across manufacturing, process, and service industries, supplier-related risks are most frequently reported as high-priority risks due to their direct impact on continuity and quality performance (Li & Zeng; Zhang & Sharifnia). Internal process risks follow closely, particularly those related to equipment reliability, production coordination, and information system failures (Dendera-Gruszka & Kulińska; Sangode). External risks, although less frequent, are characterized by high severity and systemic impact, especially in the context of pandemics and geopolitical disruptions (Bani-Irshid et al.; Goel et al.).

Comparative Results of FMEA Applications

Table 1 summarizes selected empirical findings from the reviewed studies, focusing on supply chain context, dominant risk categories, and key implications of FMEA application. The table demonstrates consistent prioritization patterns across different industrial settings, supporting the robustness of FMEA as a risk analysis tool.

Table 1. Summary of Empirical FMEA Applications in Supply Chain Risk Analysis

Author(s)	Industry Context	Dominant Risk Category	Key Implication
Li & Zeng	Manufacturing supply chain	Supplier risk	Supplier selection requires structured risk prioritization
Dendera-Gruszka & Kulińska	Heavy industry	Process risk	Modified FMEA improves process reliability
Wachyudi et al.	Biofuel supply chain	Logistics and supplier risk	Risk mapping enhances downstream coordination
Sangode	Cement industry	Process and structural risk	Integrated models improve risk hierarchy clarity
Zhang & Sharifnia	Retail supply chain	Supplier risk	FMEA supports risk-based supplier evaluation

The comparative results indicate that supplier-related failure modes frequently receive the highest Risk Priority Numbers due to combined high severity and occurrence values. These findings align with studies emphasizing the strategic role of supplier risk management in enhancing supply chain resilience.

Process and Internal Risk Assessment

Internal process risks were prominently identified in studies focusing on heavy industry, cement manufacturing, and service operations. Equipment failure, inadequate maintenance planning, and information flow disruptions were repeatedly ranked as critical failure modes (Dendera-Gruszka & Kulińska; Sangode; Gazcón-Rivera et al.). The application of modified FMEA models in these contexts demonstrates improved differentiation among risk priorities by incorporating interdependencies among processes. This finding confirms that conventional FMEA benefits from contextual adaptation without altering its core analytical structure.

External Risks and Extreme Disruptions

External risks, particularly those associated with pandemics and geopolitical conflicts, were consistently classified as high-severity but low-occurrence risks. Studies applying FMEA during the COVID-19 pandemic show that such risks significantly influence overall supply chain vulnerability despite their infrequent nature (Bani-Irshid et al.). Similarly, research addressing geopolitical disruptions emphasizes the importance of incorporating extreme-event scenarios into FMEA-based assessments to support strategic preparedness (Goel et al.). These findings demonstrate the flexibility of FMEA in addressing both operational and strategic risk dimensions.

Integrated and Hybrid FMEA Models

Several studies report enhanced analytical outcomes through the integration of FMEA with multi-criteria decision-making techniques. Hybrid models combining FMEA with AHP, PROMETHEE, fuzzy VIKOR, and interpretive structural modeling provide more consistent risk prioritization by reducing subjectivity and capturing complex relationships among risk factors (Jafari & Lohrasbi; Rathore et al.; Altubaishe & Desai). Table 2 presents a comparison of conventional and integrated FMEA approaches reported in the literature.

Table 2. Comparison of Conventional and Integrated FMEA Approaches

FMEA Approach	Analytical Focus	Reported Advantage
Conventional FMEA	Severity, occurrence, detection	Simplicity and clarity
Modified FMEA	Context-specific weighting	Improved prioritization accuracy
Integrated FMEA–MCDM	Multi-criteria evaluation	Reduced subjectivity and higher robustness

Discussion and Implications

The results confirm that Failure Mode and Effect Analysis is a robust and adaptable method for supply chain risk assessment across diverse industrial contexts. Supplier-related risks consistently emerge as dominant priorities, highlighting the importance of risk-based supplier evaluation and collaboration. Process risks underscore the need for internal reliability and coordination, while external risks emphasize strategic resilience planning. The comparative analysis demonstrates that integrating FMEA with complementary analytical methods enhances its effectiveness without compromising methodological transparency. These findings are consistent with prior empirical evidence and reinforce the relevance of FMEA as a foundational tool for supply chain risk management (Affriadi Anggara; Zhu et al.).

CONCLUSION

This study demonstrates that Failure Mode and Effect Analysis provides a systematic and reliable framework for analyzing supply chain risks across diverse industrial contexts. By synthesizing empirical findings from prior studies, the results show that supplier-related risks consistently represent the highest priority due to their combined impact on operational continuity, quality performance, and cost stability. Internal process risks, particularly those related to equipment reliability, coordination, and information flow, also emerge as critical factors that influence overall supply chain performance. In contrast, external risks such as pandemics and geopolitical disruptions, although less frequent, exhibit high severity and require strategic-level attention.

The findings confirm that FMEA is effective in supporting structured risk identification and prioritization, enabling organizations to focus mitigation efforts on the most critical failure modes. Moreover, evidence from the literature indicates that modified and integrated FMEA approaches enhance analytical robustness by reducing subjectivity and improving the treatment of complex risk relationships. These approaches strengthen the practical relevance of FMEA without altering its fundamental principles.

From a practical perspective, the results underline the importance of risk-based supplier evaluation, internal process reliability, and proactive preparedness for extreme disruptions. For researchers, this study reinforces the value of FMEA as a foundational method in supply chain risk management and highlights the benefit of synthesizing empirical evidence across sectors. Future research is encouraged to extend this line of inquiry by applying longitudinal and data-driven analyses within the established FMEA framework to further improve supply chain resilience.

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