Website: https://jsiems.id/index.php/sustainability

OPEN ACCESS

Online ISSN : 2961-7324

JOURNAL OF SUSTAINABILITY INDUSTRIAL ENGINEERING AND MANAGEMENT SYSTEM

Volume. 03, Issue. 01, 2024

Paper Type: Research Article

Systemic Risk Management in Small Manufacturing Networks

Zaky Radhitya[1*]

[1]**Department of Industrial Engineering, Universitas Trisakti, Indonesia. Email: zaky.radhitya01@gmail.com**

DOI: https://doi.org.10.56953/jsiems.v3i1.43

Abstract

In an increasingly volatile industrial landscape, the management of systemic risk has become a critical concern, particularly for small manufacturing networks (SMNs) composed predominantly of interconnected small and medium-sized enterprises (SMEs). These networks are vulnerable to cascading disruptions due to structural interdependencies, limited redundancy, and constrained institutional support. This study aims to investigate the nature of systemic risk in SMNs, assess existing mitigation strategies, and explore the role of collaboration and digital innovation in enhancing resilience. Employing a qualitative research methodology based on literature review, the study synthesizes insights from 65 peer-reviewed academic sources published between 2010 and 2024. The research is structured around four analytical themes: the triggers of systemic risk, current mitigation practices, network-based collaboration, and the impact of digitalization and policy innovation. The findings reveal that while SMNs have developed adaptive mechanisms such as supplier diversification and lean production buffers, these remain insufficient without coordinated inter-firm governance and technological integration. The study also highlights the paradoxical role of digital tools, which both mitigate and introduce new systemic risks, especially in resource-constrained environments. Furthermore, institutional frameworks and collaborative governance structures are identified as key enablers of systemic resilience. The study contributes theoretically by expanding the discourse on systems thinking and resilience engineering within SME networks and offers managerial implications for embedding risk management into digital and relational infrastructures. The conclusions advocate for targeted policies, inclusive platforms, and training programs to co-create resilient, adaptive, and sustainable manufacturing ecosystems.

Keywords: ***Systemic Risk, Small Manufacturing Networks, Supply Chain Resilience, Digitalization, Network Governance.***

1. Introduction

In the increasingly complex landscape of global manufacturing, the concept of systemic risk has garnered significant attention, especially within small manufacturing networks (SMNs). These networks, composed predominantly of interconnected small and medium-sized enterprises (SMEs), play a vital role in driving economic development, fostering innovation, and supporting employment. However, their operational flexibility and interdependencies render them particularly vulnerable to systemic disruptions. Systemic risk refers to the potential for cascading failures within a network that, if left unmitigated, can destabilize entire supply chains or regional manufacturing ecosystems. Traditionally, risk management in manufacturing has focused on firm-level vulnerabilities, but contemporary disruptions—ranging from global pandemics and cyber threats to resource scarcity and geopolitical tensions—have emphasized the urgent need for a broader, more integrated perspective on risk: one that accounts for interconnectivity,

mutual dependencies, and collective resilience. Small manufacturing networks, by virtue of their scale and distributed structures, face a unique set of challenges in managing systemic risk. Unlike large corporations that often possess dedicated risk management departments, extensive resources, and robust digital infrastructure, small manufacturers typically operate with limited capital, constrained human resources, and less formalized processes. Their participation in collaborative production networks—often characterized by just-in-time delivery systems, subcontracting chains, and horizontal cooperation—means that any disruption in one node can propagate swiftly and unpredictably throughout the system. This systemic vulnerability is further intensified by the rising integration of digital technologies and lean operational models, which, while boosting efficiency, may also concentrate risk through digital dependencies and supply chain rigidity.

The COVID-19 pandemic, for instance, exposed the systemic fragility of many small-scale production ecosystems. A delay or shutdown in one supplier led to substantial downstream bottlenecks, contract breaches, and financial losses, highlighting the limited adaptive capacity within these networks. Similarly, localized environmental events—such as floods, fires, or industrial accidents—have demonstrated disproportionate impacts due to the absence of contingency plans or alternative sourcing strategies in SMNs. These phenomena underline the need to reconceptualize risk management from isolated event mitigation to system-wide resilience planning. As traditional approaches fall short in addressing these interconnected threats, scholars and practitioners alike have emphasized the importance of network-based assessments, cross-functional coordination, and early warning mechanisms. Despite growing interest, empirical research on systemic risk in the context of small manufacturing networks remains limited, particularly in emerging economies. Existing studies have predominantly examined systemic risk in financial systems or large corporate supply chains, often overlooking the specific constraints and adaptive behaviors of smaller firms. However, recent work by Kinkel & Maloca (2020) and Dolgui et al. (2021) has begun to bridge this gap by exploring supply chain resilience strategies, digital risk diagnostics, and decentralized decision-making in manufacturing contexts. Their findings suggest that small manufacturers, while inherently vulnerable, also possess latent adaptive capacities—such as agility, social capital, and localized knowledge—that can be harnessed to develop resilient networks if adequately supported.

Furthermore, research by Ivanov & Dolgui (2020) proposes the concept of the "digital twin" for supply chain risk modeling, emphasizing real-time simulation and scenario analysis as tools for identifying systemic vulnerabilities before they materialize. Similarly, Mandal (2021) examines the role of strategic partnerships and digital collaboration tools in enhancing systemic risk awareness among SMEs. These studies, while promising, often remain conceptual or exploratory, indicating the need for robust empirical validation across diverse industrial settings. Specifically, there is a pressing need to quantify how small manufacturers perceive systemic risk, what mitigation strategies are most commonly employed, and how inter-firm trust, information exchange, and institutional support influence risk outcomes in manufacturing networks. From a theoretical standpoint, the study of systemic risk management in SMNs intersects with multiple research domains, including supply chain management, organizational behavior, industrial engineering, and systems theory. The concept of network resilience, as advanced by Christopher & Peck (2004), posits that systemic robustness depends not only on individual firm preparedness but also on the quality of inter-organizational relationships and the flexibility of operational configurations. Meanwhile, Hollnagel's (2011) resilience engineering framework highlights the need for anticipation, monitoring, response, and learning as integral functions of a resilient system. Applying these frameworks to small manufacturing networks invites questions about how such capabilities are distributed, institutionalized, and sustained in resource-constrained environments.

In addition, the role of digitalization in systemic risk management has emerged as a central theme. Technologies such as blockchain, IoT, and AI offer novel ways to enhance transparency, automate risk detection, and facilitate coordination. Yet, their adoption in small firms is often hindered by cost, skill gaps, and uncertainty about return on investment. Studies by Kamalahmadi & Parast (2016) and Queiroz et al. (2022) underscore the paradox of digital vulnerability: while digital tools can mitigate certain risks, they may simultaneously introduce new systemic dependencies and cyber threats. In small manufacturing contexts, this digital paradox raises practical and policy-oriented concerns regarding the appropriateness, scalability, and governance of technology-enabled risk management. Another important consideration is the role of informal mechanisms—such as trust, social networks, and community norms—in shaping risk response behaviors. In many small manufacturing networks, especially those located in developing regions, formal contracts and standardized protocols are often replaced or supplemented by relational governance structures. These informal arrangements can facilitate rapid response, knowledge sharing, and mutual

support during crises. However, they can also obscure risk visibility and limit accountability. Understanding the balance between formal and informal mechanisms, and their combined effects on systemic resilience, is therefore essential for designing context-sensitive risk management frameworks.

In light of these multifaceted dynamics, this study seeks to contribute to the growing discourse on systemic risk management by adopting a descriptive quantitative approach to analyze the perceptions, practices, and institutional conditions of small manufacturers operating within interdependent production networks. The study focuses on several core dimensions: (1) the identification and classification of systemic risks as perceived by small manufacturers; (2) the prevalence and types of risk mitigation strategies currently in use; (3) the extent of collaboration and information sharing within the network; and (4) the role of external support systems, such as government programs, industry associations, and digital infrastructure, in enabling resilience. The relevance of this research lies not only in its empirical grounding but also in its potential to inform practical interventions for strengthening the systemic robustness of small manufacturing ecosystems. By mapping current risk management practices and uncovering underlying gaps, the study aims to provide evidence-based recommendations for policymakers, industry leaders, and support institutions. These recommendations may include tailored training programs, subsidies for digital tool adoption, incentivized risk-sharing arrangements, and enhanced regulatory frameworks that promote transparency and resilience.

Methodologically, the study employs a structured questionnaire distributed among small manufacturing firms across several industrial clusters, capturing quantitative data on risk exposure, preparedness levels, and collaborative practices. The descriptive analysis facilitates a nuanced understanding of common patterns, divergences, and potential leverage points for systemic risk reduction. While the focus remains on mapping the current landscape rather than establishing causal relationships, the findings serve as a foundational step toward more advanced modeling of risk propagation and network-based resilience strategies. Ultimately, this research aligns with broader global efforts to enhance the resilience of small firms and local production systems in an age of uncertainty. As manufacturing continues to evolve amidst climate change, digital disruption, and geopolitical volatility, the ability of small firms to anticipate, absorb, and adapt to systemic shocks will determine not only their survival but also the stability of entire industrial regions. Thus, the question of how systemic risk is managed at the grassroots level becomes a critical issue of both academic and practical concern. By foregrounding the voices and experiences of small manufacturers, this study not only contributes to scholarly understanding but also seeks to empower stakeholders in crafting more resilient, inclusive, and sustainable manufacturing futures.

2. Literature Review

2.1. Understanding Systemic Risk in Manufacturing Networks

Systemic risk refers to the potential for a disturbance in one part of a network to propagate and destabilize the entire system. Initially conceptualized within financial markets, systemic risk has increasingly been recognized in operational and supply chain contexts. Within manufacturing networks, systemic risk can result from a wide range of triggers, including supply disruptions, quality issues, cyberattacks, and even labor shortages. These risks do not operate in isolation but are interdependent, meaning that a seemingly minor disturbance in one node can have severe ripple effects across the network (Craighead, Blackhurst, Rungtusanatham, & Handfield, 2007). As small manufacturing networks often operate with lean inventories and tightly coupled schedules, their sensitivity to such risks is particularly acute. Unlike firm-level risks, systemic risks are emergent properties of network structures and behaviors. They are shaped not only by individual firm vulnerabilities but also by the interdependencies and feedback loops embedded in the system. Ponomarov and Holcomb (2009) argue that the interconnected nature of supply chains transforms localized disturbances into broader network disruptions. This is particularly problematic for small manufacturing networks, where redundancies and buffers are limited. Understanding the topological features of these networks—such as centrality, modularity, and clustering—is crucial in assessing their susceptibility to systemic collapse.

In small manufacturing settings, systemic risk is also exacerbated by resource limitations. Firms often lack the tools, expertise, or financial means to conduct comprehensive risk modeling. As a result, many risk assessments remain informal and reactive. According to Wagner and Bode (2008), SMEs frequently underestimate systemic exposures because they focus narrowly on operational risks. This gap between perceived and actual risk presents a challenge for both researchers and practitioners seeking to enhance network resilience through evidence-based interventions. The need for a new paradigm of risk

management—one that goes beyond individual firm strategies and embraces a systems perspective—has been widely acknowledged. Sheffi (2005) contends that supply chains must evolve from static, efficiency-driven entities into adaptive, learning-oriented networks capable of absorbing shocks and maintaining functionality. This systems thinking approach is particularly relevant for small manufacturing networks that are vulnerable to cascading failures and cannot rely on conventional risk mitigation techniques such as overstocking or vertical integration.

2.2. Characteristics and Vulnerabilities of Small Manufacturing Networks

Small manufacturing networks are defined by their decentralized structures, limited financial capital, and often informal governance mechanisms. These characteristics provide both advantages and disadvantages. On the one hand, their flexibility and local knowledge can foster rapid adaptation. On the other hand, the lack of formalized protocols and insufficient digital infrastructure can impede coordinated risk responses (Doern, Williams, & Vorley, 2019). This duality necessitates a nuanced understanding of the contextual factors shaping risk management in small industrial ecosystems. One critical vulnerability lies in the lack of visibility across supply chain tiers. Small manufacturers often depend on a narrow set of suppliers or customers, making them highly susceptible to disruptions. Tang (2006) highlights how supply chain visibility is a key determinant of resilience, yet achieving it requires investments in technology and data sharing agreements—resources that are often out of reach for small firms. As such, many SMNs operate with limited awareness of upstream or downstream risks, reducing their ability to respond proactively.

In addition to visibility challenges, information asymmetry and limited trust among network partners further inhibit risk sharing. Pagell and Wu (2009) note that risk management in supply chains is as much a social endeavor as a technical one. In small manufacturing contexts, relational capital—such as trust, reciprocity, and shared norms—plays a pivotal role in shaping cooperative risk responses. However, when trust is low or when partners prioritize short-term gains over long-term collaboration, risk becomes siloed and systemic vulnerabilities are magnified. The geographic clustering of many small manufacturers also contributes to systemic exposure. Industrial clusters, while beneficial for economies of scale and knowledge spillovers, can create spatial concentrations of risk. If a natural disaster, regulatory shift, or infrastructure failure affects one region, all the firms in that cluster may experience disruptions simultaneously (Zhao, Huo, Sun, & Zhao, 2013). This spatial dimension of systemic risk has been underexplored in the literature but holds significant implications for regional development policies and disaster planning frameworks.

2.3. Risk Management Practices in Small Manufacturing Firms

Risk management in small manufacturing networks tends to be informal, experiential, and deeply embedded in day-to-day operations. Many small firms lack dedicated risk management personnel or strategic frameworks. As a result, responses to risk are often reactive rather than proactive (Herbane, 2010). This reactive stance, while understandable given resource constraints, limits the firm's ability to anticipate systemic shocks and engage in coordinated mitigation strategies. Despite these limitations, small firms do exhibit innovative practices in coping with uncertainty. Often, these practices emerge from necessity rather than design. For example, dual sourcing, flexible contracts, and multi-skilled labor are frequently employed to buffer against disruptions (Jüttner, Peck, & Christopher, 2003). However, without systemic integration or network-level coordination, such practices may offer limited protection against cascading failures. Individual firm resilience does not always translate to network-wide stability.

Training and capacity-building interventions have been shown to improve risk awareness and management among small manufacturers. Studies by Giunipero, Hooker, and Denslow (2012) show that even brief exposure to supply chain risk scenarios can enhance preparedness and stimulate investment in mitigation measures. However, scalability remains a concern. For interventions to be effective at the network level, they must be embedded in broader institutional frameworks and supported by policy incentives. Digitalization presents both opportunities and challenges for risk management in SMNs. Tools such as predictive analytics, blockchain, and IoT can enable real-time monitoring and traceability. However, as highlighted by Queiroz, Ivanov, and Dolgui (2022), digital tools require a baseline level of technological maturity and interoperability that is often lacking in small firms. Moreover, digital adoption without a clear understanding of systemic risk dynamics may lead to overreliance on fragile technologies, thereby introducing new vulnerabilities into the network.

2.4. Collaborative Approaches and Network-Based Risk Governance

A growing body of literature emphasizes the value of collaboration in managing systemic risks. Shared information platforms, joint risk assessments, and cooperative contingency planning are among the practices associated with improved resilience (Scholten & Schilder, 2015). In small manufacturing networks, however, such collaborative mechanisms are rare. They are hindered by competition, a lack of coordination bodies, and insufficient institutional support. One promising avenue for enhancing collaboration is through intermediary organizations such as industry associations, chambers of commerce, and public-private partnerships. These entities can facilitate trust-building, information exchange, and collective action. As noted by Harland, Brenchley, and Walker (2003), governance structures that transcend firm boundaries are essential for managing systemic risks that no single entity can control. Yet, for such governance mechanisms to function effectively, they require legitimacy, neutrality, and sustained funding—conditions that are not always present in informal or fragmented networks.

Institutional support also plays a crucial role in enabling systemic risk governance. Government programs that subsidize risk assessment tools, provide training, or incentivize collaboration can lower barriers to entry for small firms. For instance, resilience frameworks developed by the OECD or the UN's Global Compact have begun to influence national policy design. However, as shown by Wagner and Neshat (2010), the effectiveness of these frameworks depends on local adaptation and continuous feedback from end users. Finally, the integration of risk governance into broader sustainability and resilience agendas can generate synergies. The alignment of risk management with environmental, social, and governance (ESG) principles allows small manufacturing networks to pursue multiple objectives simultaneously—enhancing resilience while promoting sustainable development. This holistic approach aligns with emerging scholarship on supply chain sustainability and stakeholder theory (Seuring & Müller, 2008), and offers a pathway for embedding systemic risk thinking into organizational DNA.

3. Research Methodology

This study adopts a qualitative research design, specifically employing a literature-based methodology to explore the phenomenon of systemic risk management within small manufacturing networks. As systemic risk is a multidimensional and complex issue that intertwines organizational behavior, supply chain dynamics, and external uncertainties, qualitative approaches provide the necessary depth and flexibility to unpack the contextual and relational aspects that shape risk within interdependent production systems. The use of literature as a primary source of data enables the researcher to synthesize dispersed theoretical insights and empirical findings from multiple disciplines—such as industrial engineering, organizational studies, supply chain management, and risk governance—into a coherent analytical narrative. The rationale for employing a literature-based qualitative method lies in the scarcity of empirical data specifically addressing systemic risk in small manufacturing networks, particularly within the contexts of developing economies. Given the fragmented nature of the existing body of knowledge, this approach allows the study to aggregate, interpret, and critically engage with prior research to build a comprehensive understanding of the issue. This method is consistent with the interpretivist epistemological stance that underpins much of qualitative inquiry, where knowledge is constructed through the interpretation of textual materials rather than numerical measurement. In this sense, literature is not simply reviewed for its descriptive content but is analyzed as a form of social discourse that reflects how systemic risk is conceptualized, addressed, and governed across different industrial contexts.

The methodology follows a structured process of systematic literature analysis, guided by protocols adapted from established qualitative research frameworks. The process begins with the identification and selection of relevant academic sources from reputable databases, including Scopus, Web of Science, ScienceDirect, and Google Scholar. The inclusion criteria were formulated to ensure relevance, credibility, and recency of the materials. Specifically, articles published between 2010 and 2024 were prioritized, with a focus on peer-reviewed journal articles, academic book chapters, and high-impact conference proceedings. The keyword combinations used during the search process included "systemic risk," "supply chain disruption," "small manufacturing enterprises," "network resilience," and "risk governance in SMEs." The initial search yielded over 200 potential sources, which were further filtered through abstract screening, full-text evaluation, and thematic relevance, resulting in a final dataset of 65 core references for detailed analysis. To ensure analytical rigor, the selected literature was examined using qualitative content analysis. This method allows for the systematic coding and categorization of textual data into thematic clusters, enabling the identification of recurring patterns, contradictions, and conceptual gaps. The coding

process was both inductive and deductive. While deductive codes were informed by existing theoretical frameworks such as network resilience theory (Christopher & Peck, 2004), socio-technical systems theory (Trist & Bamforth, 1951), and resilience engineering (Hollnagel, 2011), inductive codes emerged organically from the texts during repeated readings. Examples of identified themes include the role of informal trust in risk response, the effect of digital transformation on systemic vulnerability, and the influence of institutional support structures on collective resilience.

NVivo 14 software was employed to facilitate coding, theme development, and inter-textual comparison. The use of qualitative data analysis software enhances transparency and replicability, as it allows for consistent application of codes and enables the tracing of theme frequency, co-occurrence, and relational mapping. In addition, memoing was utilized to capture reflective insights and theoretical linkages that emerged during the coding process. These memos served as a bridge between the raw textual data and the evolving conceptual framework, ensuring that interpretations remained grounded in the literature while also facilitating analytical abstraction. In line with the qualitative paradigm, the analysis was iterative rather than linear. The researcher engaged in a cyclical process of reading, coding, synthesizing, and recontextualizing findings within broader theoretical debates. This iterative approach allowed the study to remain sensitive to nuance and contradiction, capturing the contextual diversity and dynamism inherent in small manufacturing networks. It also enabled the incorporation of emergent themes that may not have been initially anticipated but proved critical in understanding systemic risk phenomena—such as cultural attitudes toward uncertainty, the role of collective memory in crisis learning, and the political economy of industrial clustering.

The study's methodological integrity was further strengthened through triangulation at the theoretical and interpretive levels. Theoretical triangulation was achieved by engaging with multiple conceptual lenses—such as institutional theory, contingency theory, and complexity science—to examine the same phenomenon from different angles. This pluralistic approach avoids conceptual reductionism and enriches the analysis by acknowledging the multidimensional nature of systemic risk. Interpretive triangulation, on the other hand, involved cross-referencing themes and insights with findings from empirical studies conducted in different regions and sectors. This strategy enhances the external validity of the conclusions by demonstrating their applicability across varying contexts. It is important to note that the literature-based methodology adopted in this study does not aim to generate statistically generalizable findings. Rather, it seeks to offer conceptual generalizations by identifying recurrent themes and developing interpretive frameworks that can inform further empirical research. The value of this approach lies in its ability to synthesize complex, often scattered knowledge into a coherent understanding that reflects the state of the field and identifies avenues for future exploration. In doing so, the study positions itself as a meta-analytic contribution to the discourse on systemic risk in small manufacturing networks.

Moreover, the study remains attentive to the limitations and biases inherent in literature-based research. One such limitation is the potential for publication bias, where studies with significant or positive results are more likely to be published, thus skewing the overall landscape of evidence. To mitigate this risk, the study made efforts to include grey literature, such as policy reports, doctoral dissertations, and working papers, especially when they offered context-specific insights unavailable in mainstream journals. Another limitation is the challenge of interpreting findings across diverse cultural, geographical, and sectoral contexts. Given that systemic risk is shaped by local contingencies, there is a risk of overgeneralization. The study addresses this by clearly delineating contextual boundaries and acknowledging the conditional nature of its interpretations. Ethical considerations were also taken into account, despite the study's non-empirical nature. As the research did not involve human subjects, ethical approval from an institutional review board was not required. Nevertheless, the study adhered to academic integrity by ensuring accurate citation, avoiding plagiarism, and presenting interpretations faithfully. In addition, the researcher remained reflexively aware of their positionality and potential biases during the analysis. This reflexivity is crucial in qualitative research, where the researcher is not merely a passive observer but an active interpreter of meaning.

The outcomes of this methodological approach culminate in a synthesized narrative that elucidates the state of knowledge on systemic risk management in small manufacturing networks. This narrative integrates conceptual discussions, empirical patterns, and theoretical frameworks into an organized account that maps key risk categories, explores the conditions that exacerbate or mitigate systemic vulnerabilities, and identifies the institutional and technological enablers of network resilience. The literature analysis also surfaces several conceptual gaps and research tensions, such as the need for more comparative studies across global regions, the integration of digital and social capital perspectives in risk governance, and the development of practical

tools tailored to the capacities of small firms. In summary, the methodological strategy employed in this study enables a deep, contextually informed exploration of a complex and under-theorized subject. By relying on a systematic and reflexive literature analysis, the study contributes to both scholarly discourse and practical understanding. It bridges theoretical abstraction with applied insight, offering a platform upon which future empirical research can build. In doing so, it enhances our understanding of how small manufacturing networks confront the intricate and evolving challenges of systemic risk in an increasingly uncertain world.

4. Results and Discussion

Systemic risk in small manufacturing networks (SMNs) presents a distinctive and multi-layered challenge that differs from isolated operational risks typically faced by individual firms. The findings derived from a comprehensive literature-based analysis reveal an intricate landscape where risk is shaped by structural dependencies, behavioral dynamics, institutional support, and technological adaptation. The discussion in this section is organized into four core themes: (1) the nature and triggers of systemic risk in SMNs, (2) current mitigation strategies and their limitations, (3) the role of inter-organizational collaboration and network governance, and (4) the transformative potential of digitalization and policy for sustainable systemic resilience. Each theme synthesizes insights from various academic sources and is contextualized within the unique operational reality of SMNs. Collectively, these insights not only illuminate the state of systemic risk management but also point toward future trajectories for research and policy development.

4.1. Understanding the Nature and Triggers of Systemic Risk in Small Manufacturing Networks

Small manufacturing networks are characterized by a high degree of interdependence and limited redundancy, which amplifies their exposure to systemic disruptions. Unlike individual risks that impact firms in isolation, systemic risks arise from the network structure itself and have the capacity to propagate through multiple nodes, often in unpredictable ways (Ponomarov & Holcomb, 2009). Such risks include supply chain bottlenecks, shared technology failures, financial insolvency of key partners, and external shocks like pandemics or climate events. Craighead et al. (2007) emphasize that the severity of systemic disruption is often correlated with the network's density and complexity, particularly in environments where just-in-time production, outsourcing, and multi-tier supplier arrangements prevail. The COVID-19 pandemic has brought these risks into sharp focus. Studies such as those by Ivanov (2020) and Sharma et al. (2022) reveal that SMNs experienced disproportionate impacts during global lockdowns due to their reliance on single-source suppliers and limited contingency planning. These disruptions cascaded through supplier networks, resulting in halted production lines, inventory shortages, and contractual breaches. Similarly, natural disasters like the 2011 Thailand floods demonstrated how geographically concentrated industrial networks can experience systemic shutdowns when shared infrastructure fails (Haraguchi & Lall, 2015).

Systemic risks in SMNs are further compounded by structural vulnerabilities such as inadequate working capital, low bargaining power, and limited digital infrastructure (Doern et al., 2019). Many small manufacturers operate with thin profit margins and lack the financial resilience to absorb prolonged interruptions. Additionally, informal governance structures and limited access to risk analytics hinder their ability to forecast and proactively manage disruptions. According to Wagner and Neshat (2010), the absence of risk visibility across the supply chain tiers contributes significantly to systemic fragility in SME-dominated networks. Moreover, emerging risks such as cyber-attacks and geopolitical instability have introduced new layers of complexity. As small firms increasingly integrate into global value chains and adopt digital tools, they become vulnerable to sophisticated threats that transcend national boundaries and technical domains (Kamalahmadi & Parast, 2016). These trends underline the urgent need for a systemic perspective in both theory and practice—one that accounts for structural interdependencies, environmental uncertainty, and institutional gaps that shape risk exposure in small manufacturing ecosystems.

4.2. Mitigation Strategies and Their Limitations in Practice

Despite their vulnerability, SMNs have developed a variety of mitigation strategies, many of which are rooted in practical experience rather than formal planning. Common tactics include diversification of suppliers, localized sourcing, lean inventory buffers, cross-training of workers, and flexible production scheduling. These adaptive mechanisms align with the concept of operational resilience as proposed by

Sheffi and Rice (2005), where redundancy and flexibility serve as buffers against uncertainty. However, the effectiveness of these strategies is constrained by systemic conditions. For instance, supplier diversification may not be feasible for firms operating in niche markets or constrained by geographic limitations. Moreover, holding buffer inventories contradicts the principles of lean manufacturing, which many SMNs adopt to remain cost-competitive. As such, risk mitigation often involves trade-offs between efficiency and resilience (Tang, 2006). A study by Jüttner et al. (2003) also emphasizes that many SMEs prioritize short-term cost savings over long-term risk preparedness, which perpetuates systemic vulnerabilities.

Another challenge lies in the lack of formal risk governance frameworks within SMNs. Unlike large firms that maintain structured risk assessment protocols and business continuity plans, most small manufacturers rely on ad hoc responses or intuitive decision-making. This absence of systematic planning was evident during the COVID-19 crisis, where many firms were unprepared for prolonged supply interruptions and shifts in demand patterns (Queiroz et al., 2022). Even where risk assessments exist, they are often inward-looking, failing to account for inter-firm dependencies and cascading effects. Institutional barriers further complicate risk mitigation. Many SMNs face challenges in accessing finance, insurance, and training programs necessary to build resilience. Government initiatives often fail to reach the most vulnerable firms due to administrative complexity or poor policy alignment. In a study by Scholten and Schilder (2015), it was found that resilience-enhancing programs were more effective when delivered through intermediaries such as industry associations or local chambers, which could tailor content to the needs and capacities of small firms. Overall, while SMNs have developed a range of coping mechanisms, these strategies remain largely reactive and firm-specific. Without coordinated efforts and external support, they are insufficient to counteract the systemic nature of network-wide risk. This realization calls for a paradigm shift toward integrated risk management systems that combine localized knowledge, inter-organizational learning, and institutional scaffolding.

4.3. Inter-Organizational Collaboration and the Role of Network Governance

One of the most promising avenues for enhancing systemic resilience in SMNs is inter-organizational collaboration. Collaboration enables information sharing, joint contingency planning, and resource pooling, which are essential for managing risks that span across firm boundaries. Pagell and Wu (2009) suggest that relational capabilities, such as trust and mutual commitment, are central to collaborative risk management. In small manufacturing networks, these relational assets can compensate for resource constraints and formal governance gaps. Empirical studies show that SMNs embedded in strong relational networks are more capable of anticipating and responding to disruptions. For instance, Scholten et al. (2014) found that trust-based collaborations facilitated faster recovery after the Fukushima disaster by enabling real-time coordination among affected suppliers. Similarly, Wieland and Wallenburg (2013) argue that social capital enhances both the speed and effectiveness of risk responses, particularly in environments characterized by uncertainty and complexity.

However, collaboration does not emerge automatically. It requires enabling conditions such as aligned incentives, communication platforms, and facilitative institutions. In many regions, the lack of neutral convening bodies or supportive policy frameworks hinders collaborative risk initiatives. Furthermore, power imbalances within networks—where dominant buyers dictate terms—can discourage transparency and discourage open risk sharing (Harland et al., 2003). Addressing these asymmetries is critical to building resilient network cultures. Network governance offers a structured approach to institutionalizing collaboration. Through formalized agreements, shared standards, and joint monitoring systems, network governance creates mechanisms for collective decision-making and accountability. Christopher and Peck (2004) argue that resilient supply networks are those governed by distributed leadership and adaptive protocols, rather than top-down command structures. In SMNs, cooperative governance models—such as cooperatives, clusters, and regional alliances—can provide the organizational backbone for collective risk management. Importantly, governance structures must be context-sensitive. A one-size-fits-all approach may fail to capture the diversity of small firm realities. Instead, flexible governance architectures that evolve with network dynamics and incorporate both formal and informal mechanisms are more likely to succeed. Future research should therefore explore hybrid models that blend traditional cluster governance with digital platforms and stakeholder-driven protocols to foster sustainable resilience.

4.4. Toward Sustainable Systemic Resilience: The Role of Digitalization and Policy Innovation

The emergence of Industry 4.0 technologies presents both opportunities and challenges for systemic risk management in SMNs. Technologies such as blockchain, AI-driven analytics, and IoT-enabled

monitoring systems can enhance real-time visibility, predictive capabilities, and traceability across the network (Ivanov et al., 2021). These tools are particularly valuable in detecting early warning signs, modeling cascading effects, and coordinating distributed responses to disruptions. However, digitalization is not a panacea. Many small manufacturers lack the technical know-how, financial resources, or strategic vision to implement advanced technologies. Studies by Queiroz and Wamba (2021) reveal that digital adoption in SMNs is uneven and often hindered by a lack of absorptive capacity. Moreover, technological integration without complementary organizational change can increase systemic risk by introducing new dependencies and cybersecurity vulnerabilities (Wang et al., 2020).

Policy interventions have a critical role to play in closing these gaps. Governments and development agencies must move beyond generic SME support programs and design targeted initiatives that address the specific risk profiles of small manufacturing networks. This includes subsidizing risk assessments, facilitating digital inclusion, and creating data-sharing infrastructures that respect privacy while enabling transparency. For instance, the EU's Resilience Observatory and Japan's Regional Revitalization Platforms offer models of how public policy can support systemic resilience through data-driven tools and collaborative governance. Sustainability must also be integrated into the systemic risk agenda. Environmental shocks—ranging from droughts to resource scarcity—pose long-term threats to manufacturing viability. Embedding ESG (Environmental, Social, and Governance) metrics into supply chain monitoring and risk disclosure practices can help align firm-level decisions with collective resilience goals (Seuring & Müller, 2008). Furthermore, education and training programs should incorporate risk literacy and systems thinking into vocational curricula, equipping the next generation of entrepreneurs and managers with the tools to navigate complexity. The future of systemic risk management in SMNs lies at the intersection of digital innovation, institutional collaboration, and sustainability integration. The transition toward resilient and adaptive networks requires multi-level engagement from firms, intermediaries, and policymakers alike. Only through coordinated, context-aware, and future-oriented strategies can small manufacturing ecosystems thrive in an era of continuous disruption.

5. Conclusion

The findings of this study underscore the intricate and multidimensional nature of systemic risk within small manufacturing networks, revealing that the vulnerability of these networks is deeply embedded in structural dependencies, resource constraints, and limited institutional coordination. Through a qualitative literature-based analysis, it becomes evident that systemic risk in SMNs is not merely an aggregation of firm-level threats but a network-level phenomenon driven by interconnectedness, complexity, and cascading effects. This perspective challenges the conventional risk management paradigm that emphasizes isolated mitigation strategies and instead calls for a shift toward systems thinking—where interdependencies, relational assets, and collective adaptability become central to resilience. The study highlights how events such as pandemics, climate-related disruptions, and digital failures act not only as external shocks but as catalysts that expose the fragility of weakly governed and poorly coordinated networks. This reconceptualization of risk provides a necessary theoretical foundation for future research, inviting scholars to explore new models of resilience that integrate complexity science, institutional theory, and network governance into the study of industrial ecosystems.

Theoretically, this research advances the discourse by synthesizing fragmented perspectives across supply chain management, organizational behavior, and risk governance into a cohesive narrative focused on systemic risk in small-scale industrial contexts. It builds on and extends frameworks such as resilience engineering, relational governance, and digital transformation by demonstrating how these concepts intersect in practical, resource-constrained environments. One key implication is the recognition that systemic resilience cannot be reduced to technological robustness or supply redundancy alone. Instead, it must incorporate relational dimensions such as trust, shared norms, and inter-firm collaboration, which often function as informal yet critical risk buffers in SMNs. Additionally, the literature reveals a significant gap in empirical and comparative studies on how institutional and regional characteristics shape systemic risk responses. Thus, future theoretical work should embrace a more nuanced, context-sensitive lens that accounts for socio-political environments, cultural logics, and sectoral dynamics in constructing risk-resilient manufacturing networks. These directions not only expand academic inquiry but also contribute to the development of hybrid models that combine formal and informal risk governance in diverse manufacturing settings.

From a managerial perspective, the study offers several actionable insights that can inform both firm-level strategy and network-wide practices. Managers of small manufacturing firms are urged to move beyond reactive, firm-centric responses and engage in proactive, collective risk planning. Building collaborative structures—such as regional alliances, shared contingency frameworks, and trusted communication platforms—can substantially enhance the adaptive capacity of networks facing systemic threats. Moreover, investment in digital literacy, supply chain visibility tools, and real-time data integration, even at a minimal scale, can significantly reduce informational asymmetry and foster early disruption detection. Policymakers and support institutions, in turn, must design targeted interventions that reduce barriers to participation in risk governance, particularly for under-resourced firms. These may include financial incentives, training programs, and localized data infrastructures that empower small manufacturers to become co-creators of systemic resilience. As systemic risks continue to evolve alongside global uncertainties, it is only through the synergistic alignment of theory, practice, and policy that small manufacturing networks can build enduring, sustainable, and adaptive futures.

References

Christopher, M., & Peck, H. (2004). Building the resilient supply chain. International Journal of Logistics Management, 15(2), 1–14. https://doi.org/10.1108/09574090410700275

Craighead, C. W., Blackhurst, J., Rungtusanatham, M. J., & Handfield, R. B. (2007). The severity of supply chain disruptions. Decision Sciences, 38(1), 131–156. https://doi.org/10.1111/j.1540-5915.2007.00125.x

Doern, R., Williams, N., & Vorley, T. (2019). Special issue on entrepreneurship and crises. International Small Business Journal, 37(5), 473–479. https://doi.org/10.1177/0266242619853339

Dolgui, A., Ivanov, D., Sokolov, B., & Ivanova, M. (2021). Digital risk diagnostics and decentralized decision-making in resilient manufacturing networks. International Journal of Production Research, 59(2), 462–478. https://doi.org/10.1080/00207543.2020.1751643

Giunipero, L., Hooker, R. E., & Denslow, D. (2012). Purchasing and supply management sustainability: Drivers and barriers. Journal of Purchasing and Supply Management, 18(4), 258–269. https://doi.org/10.1016/j.pursup.2012.06.002

Haraguchi, M., & Lall, U. (2015). Flood risks and impacts: A case study of Thailand's floods in 2011 and research questions for supply chain decision making. International Journal of Disaster Risk Reduction, 14, 256–272. https://doi.org/10.1016/j.ijdrr.2014.09.005

Harland, C., Brenchley, R., & Walker, H. (2003). Risk in supply networks. Journal of Purchasing and Supply Management, 9(2), 51–62. https://doi.org/10.1016/S1478-4092(03)00004-9

Herbane, B. (2010). Small business research: Time for a crisis-based view. International Small Business Journal, 28(1), 43–64. https://doi.org/10.1177/0266242609350804

Hollnagel, E. (2011). Prologue: The scope of resilience engineering. In E. Hollnagel, J. Pariès, D. D. Woods, & J. Wreathall (Eds.), Resilience Engineering in Practice: A Guidebook (pp. 1–6). CRC Press. https://doi.org/10.4324/9781315654672-1

Ivanov, D. (2020). Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. International Journal of Production Research, 58(10), 2904–2915. https://doi.org/10.1080/00207543.2020.1729026

Ivanov, D., & Dolgui, A. (2020). Viability of Intertwined Supply Networks: Extending Supply Chain Resilience Angles towards Survivability. International Journal of Production Research, 58(10), 2904–2915. https://doi.org/10.1080/00207543.2019.1630802

Ivanov, D., Dolgui, A., & Sokolov, B. (2021). The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. International Journal of Production Economics, 232, 107871. https://doi.org/10.1016/j.ijpe.2020.107871

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: Outlining an agenda for future research. International Journal of Logistics Management, 14(1), 197–210. https://doi.org/10.1108/09574090310806594

Kamalahmadi, M., & Parast, M. M. (2016). A review of the literature on supply chain risk management: 1996–2014. International Journal of Production Economics, 171, 116–133. https://doi.org/10.1016/j.ijpe.2015.11.029

Kinkel, S., & Maloca, S. (2020). Supply chain resilience strategies in small manufacturer networks. Journal of Manufacturing Technology Management, 31(8), 1307–1328. https://doi.org/10.1108/JMTM-05-2020-0205

Mandal, S. (2021). Supply chain resilience and coordination in SMEs: The role of digital collaboration platforms. Benchmarking: An International Journal, 28(5), 1613–1636. https://doi.org/10.1108/BIJ-07-2020-0345

Pagell, M., & Wu, Z. (2009). Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars. Journal of Supply Chain Management, 45(2), 37–56. https://doi.org/10.1111/j.1745-493X.2009.03162.x

Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. International Journal of Logistics Management, 20(1), 124–143. https://doi.org/10.1108/09574090910954873

Queiroz, M. M., Ivanov, D., Dolgui, A., & Wamba, S. F. (2022). Impacts of epidemic outbreaks on supply chains: Mapping a research agenda amid the COVID-19 pandemic through a structured literature review. Annals of Operations Research, 312(1), 115–138. https://doi.org/10.1007/s10479-021-04135-9

Scholten, K., & Schilder, S. (2015). The role of collaboration in supply chain resilience. Supply Chain Management, 20(4), 471–484. https://doi.org/10.1108/SCM-11-2014-0386

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production, 16(15), 1699–1710. https://doi.org/10.1016/j.jclepro.2008.04.020