The Roles of Agility, Supply Chain Sustainability, and Risk Management on Operations Performance in Manufacturing Industry

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ABSTRACT

This study investigates the role of sustainable supply chain practices and risk management in enhancing manufacturing agility and operational performance, with a particular focus on the underexplored context of developing countries such as Indonesia. Data were collected from 255 managers and executives across the manufacturing, operations, logistics, and supply chain sectors using a structured questionnaire based on a five-point Likert scale. The responses were analyzed using SmartPLS. The results indicate that environmental practices positively influence both manufacturing agility and operational performance, although the effect on operational performance is relatively weaker yet remains statistically significant. Risk management emerges as a critical enabler, contributing positively to both agility and performance outcomes. Among the variables examined, manufacturing agility exerts the strongest influence on operational performance, underscoring its pivotal role in achieving competitive advantage. By integrating supply chain sustainability, risk management, manufacturing agility, and operational performance into a unified framework, this study addresses key research gaps and provides valuable theoretical and practical insights.

Keywords*: Manufacturing Agility, Operations Performance, Risk Management, Supply Chain, Sustainability.*

ABSTRAK

Studi ini menyelidiki peran praktik rantai pasokan berkelanjutan dan manajemen risiko dalam meningkatkan kelincahan manufaktur dan kinerja operasional, dengan fokus khusus pada konteks negara berkembang yang belum banyak dieksplorasi seperti Indonesia. Data dikumpulkan dari 255 manajer dan eksekutif di seluruh sektor manufaktur, operasi, logistik, dan rantai pasokan menggunakan kuesioner terstruktur berdasarkan skala Likert lima poin. Respons dianalisis menggunakan SmartPLS. Hasilnya menunjukkan bahwa praktik lingkungan memengaruhi kelincahan manufaktur dan kinerja operasional secara positif, meskipun pengaruhnya terhadap kinerja operasional relatif lebih lemah tetapi tetap signifikan secara statistik. Manajemen risiko muncul sebagai pendorong penting, yang berkontribusi positif terhadap kelincahan dan hasil

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kinerja. Di antara variabel yang diperiksa, kelincahan manufaktur memberikan pengaruh paling kuat terhadap kinerja operasional, yang menggarisbawahi perannya yang penting dalam mencapai keunggulan kompetitif. Dengan mengintegrasikan keberlanjutan rantai pasokan, manajemen risiko, kelincahan manufaktur, dan kinerja operasional ke dalam kerangka kerja terpadu, studi ini mengatasi kesenjangan penelitian utama dan memberikan wawasan teoritis dan praktis yang berharga.

Kata kunci: *Kelincahan Manufaktur, Kinerja Operasi, Manajemen Risiko, Rantai Pasokan, Keberlanjutan.*

INTRODUCTION

In recent years, global supply chains have experienced profound transformations driven by technological advancements, growing sustainability demands, and an increased focus on risk management. The rise of Industry 4.0 technologies, such as automation and the Internet of Things (IoT), has revolutionized operational frameworks, enabling firms to enhance efficiency and responsiveness (Zhang et al., 2022; Arif et al., 2024). Concurrently, disruptions like the COVID-19 pandemic have exposed vulnerabilities in supply chains, emphasizing the need for agility to navigate unpredictable market conditions (Guo et al., 2020; Sari et al., 2025). These dynamics have compelled organizations to integrate sustainable practices and robust risk management strategies to ensure resilience and competitiveness. For instance, Sustainable Supply Chain Management (SSCM) not only addresses environmental and social concerns but also fosters operational adaptability, aligning with long-term strategic goals (Golicic & Smith, 2013; Febrianto et al., 2024). This evolving landscape underscores the importance of aligning supply chain strategies with agility and resilience to thrive in volatile global markets.

Despite significant advancements in supply chain management, critical research gaps persist, particularly in understanding how risk management, sustainable practices, and manufacturing agility collectively influence operations performance in developing economies like Indonesia. According to Inman and Green (2021) and Fahmie et al. (2025), most studies have focused on developed nations, where resource availability and infrastructure differ significantly from emerging markets. This oversight neglects the unique challenges in developing economies, such as limited resources, infrastructural constraints, and evolving regulatory frameworks, which create distinct operational dynamics (Sánchez-Flores et al., 2020; Rainanto et al., 2025). Furthermore, Yaakub and Mustafa (2022) and Wibowo (2025) highlight that while the individual impacts of risk management and sustainability on performance are well-established, their combined effects and the mediating role of agility remain underexplored. This gap is particularly pronounced in contexts like Indonesia, where the manufacturing sector, a key economic driver, faces unique pressures from global competition and local constraints (Nugroho et al., 2024). Addressing these gaps is crucial for developing context-specific strategies that enhance supply chain performance in resource-constrained environments.

The novelty of this study lies in its integrated approach to examining the interplay of risk management, sustainable supply chain practices, and manufacturing agility on operations performance within Indonesia's manufacturing sector. By focusing on a developing economy, this research addresses the aforementioned gaps and provides insights into strategic priorities for firms operating in similar settings. The incorporation of sustainability into risk management and agility frameworks offers a fresh perspective, aligning operational strategies with long-term resilience and competitive advantage (Ngo et al., 2023; Siregar et al., 2025). Additionally, the study explores how these constructs interact to drive operational excellence, contributing to a more holistic understanding of supply chain dynamics in emerging markets. This approach not only fills theoretical voids but also offers practical guidance for firms navigating complex and volatile environments.

The objectives of this research are twofold. First, it aims to empirically investigate the relationships among sustainable supply chain practices, risk management, manufacturing

agility, and operations performance in the Indonesian manufacturing context. Second, it seeks to identify the mechanisms through which these factors interact to enhance supply chain success, providing actionable insights for practitioners and policymakers. By addressing these objectives, the study contributes to the theoretical development of supply chain resilience frameworks, emphasizing the role of agility as a mediator. Practically, it offers strategies for integrating sustainability and risk management to improve adaptability and performance in volatile markets.

LITERATURE REVIEW & HYPOTHESIS DEVELOPMENT

Risk Management and Manufacturing Agility

Risk management in Supply Chain Management (SCM) encompasses systematic processes to identify, assess, mitigate, and monitor risks, ensuring operational resilience and continuity. According to Indarbaev and Kapustina (2023) and Sujana and Yusni (2024), effective risk management mitigates disruptions from operational inefficiencies, supply chain interruptions, and external uncertainties, fostering adaptability in dynamic environments. Real-time monitoring and contingency planning enable firms to anticipate disruptions, enhancing their ability to respond swiftly to market changes (Berliana & Mashadi, 2022; Hsu et al., 2022; Purba, 2022; Aisyah et al., 2024). This adaptability is crucial in volatile markets, particularly in developing economies like Indonesia, where infrastructural and regulatory challenges amplify risks.

Predictive tools, such as risk assessment models, allow organizations to foresee supply chain vulnerabilities, enabling rapid adjustments in production processes (Wiengarten et al., 2016; Almulla, 2022). Such practices minimize the adverse effects of disruptions, ensuring operational continuity and flexibility. Braunscheidel and Suresh (2009) emphasize that scenario planning and proactive risk mitigation enhance a firm's capacity to navigate uncertainties, a critical factor in maintaining manufacturing agility. In the Indonesian context, where supply chain disruptions are frequent due to logistical constraints, risk management provides a strategic foundation for agility. Furthermore, integrating risk management with digital technologies, such as IoT-based monitoring systems, strengthens responsiveness, enabling firms to adapt to fluctuating demands (Nugroho et al., 2024). By aligning risk management with organizational goals, firms can maintain operational flexibility, ensuring competitiveness in global markets. This capability is particularly vital for manufacturers facing high uncertainty, where proactive risk mitigation translates into a competitive advantage, supporting agile manufacturing systems.

H1: Risk management has a positive impact on manufacturing agility.

Sustainable Supply Chain Management and Manufacturing Agility

Sustainable Supply Chain Management (SSCM) integrates environmental, social, and economic considerations to promote long-term viability while minimizing adverse impacts. Gouda and Saranga (2018) highlight that SSCM fosters innovation through environmentally friendly practices, such as material recycling and reuse, which reduce dependency on finite resources. These practices enable manufacturers to adapt quickly to supply shortages or disruptions, enhancing agility (Golicic & Smith, 2013). Compliance with environmental regulations drives process innovation, increasing the flexibility and responsiveness of manufacturing systems. For instance, closed-loop systems allow firms to recycle materials efficiently, ensuring resource availability during disruptions (Panigrahi et al., 2019).

In developing economies like Indonesia, where resource constraints are prevalent, SSCM provides a strategic advantage by enabling operational flexibility. Zhang et al. (2022) note that green supply chain integration streamlines processes, reducing environmental risks and enhancing agility. Collaboration with supply chain partners further facilitates rapid adjustments to market demands, a key component of agile manufacturing (Khan et al., 2021). Additionally, SSCM promotes the adoption of

Industry 4.0 technologies, such as smart logistics systems, which enhance responsiveness to market changes (Men et al., 2023). In Indonesia's manufacturing sector, sustainable practices mitigate risks associated with resource scarcity, ensuring firms can maintain production continuity. By fostering innovation and collaboration, SSCM not only supports environmental goals but also strengthens manufacturing agility, enabling firms to thrive in dynamic and competitive markets.

H2: Sustainable supply chain management has a positive impact on manufacturing agility.

Risk Management and Operations Performance

Risk management is pivotal in enhancing operations performance by ensuring efficiency and continuity in supply chain operations. Gurtu and Johny (2021) assert that early risk identification and mitigation prevent costly disruptions, thereby improving operational efficiency. Predictive tools and real-time monitoring enable seamless operations, critical for meeting performance targets (Wiengarten et al., 2016). By proactively addressing risks, firms avoid inefficiencies caused by supply chain interruptions or external uncertainties, ensuring consistent delivery of goods and services. In Indonesia's manufacturing sector, where logistical and regulatory challenges are prevalent, risk management is essential for sustaining reliability (Indarbaev & Kapustina, 2023).

Contingency planning allows manufacturers to maintain production schedules despite disruptions, directly supporting performance goals. Men et al. (2023) emphasize that robust risk management frameworks optimize resource allocation, reducing waste and enhancing cost-effectiveness. Furthermore, integrating risk management with digital tools, such as AI-driven forecasting, enhances operational precision, enabling firms to meet customer expectations efficiently (Nugroho et al., 2024). In volatile markets, risk management ensures operational continuity, a cornerstone of performance. By aligning risk mitigation with strategic objectives, firms can achieve consistent quality and delivery, critical for maintaining competitiveness in global supply chains.

H3: Risk management has a positive impact on operations performance.

Sustainable Supply Chain Management and Operations Performance

SSCM significantly enhances operations performance by optimizing resource utilization and reducing environmental impact in Indonesian manufacturing industry. Sánchez-Flores et al. (2020) highlight that practices like recycling and reuse lower production costs while minimizing ecological footprints, directly improving operational efficiency. Closed-loop systems enable firms to manage resources effectively, ensuring consistent performance even in resource-constrained environments like Indonesia, where raw material availability can be unpredictable (Panigrahi et al., 2019). Compliance with environmental regulations fosters innovation, streamlining processes and enhancing sustainability, which contributes to cost savings and reliable delivery schedules (Khan et al., 2021). For instance, adopting waste reduction initiatives not only lowers operational costs but also aligns with global sustainability standards, enhancing market competitiveness.

In Indonesia, where regulatory pressures are increasing due to environmental policies, SSCM provides a strategic framework for balancing profitability with ecological responsibility (Golicic & Smith, 2013). Ngo et al. (2023) note that sustainable practices strengthen supply chain resilience by mitigating risks associated with resource scarcity, indirectly boosting performance. The integration of green technologies, such as energy-efficient production systems and IoT-enabled supply chain tracking, further enhances operational efficiency by reducing energy consumption and improving process transparency (Zhang et al., 2022). Additionally, SSCM fosters collaboration with stakeholders, enabling firms to optimize supply chain processes and respond effectively

to market demands (Hsu et al., 2022). In developing economies, where infrastructure limitations pose challenges, sustainable practices ensure long-term operational success by reducing dependency on external resources and enhancing adaptability. By aligning environmental, social, and economic goals, SSCM supports operational excellence, ensuring firms remain competitive in volatile global markets while contributing to Sustainable Development Goals (SDGs).

H4: Sustainable supply chain management has a positive impact on operations performance.

Manufacturing Agility on Operations Performance

Manufacturing agility enables firms to optimize resources and adapt swiftly to market changes, directly enhancing operations performance in Indoneisa manufacture Industry. Abdelilah et al. (2021) assert that agile manufacturing systems allow firms to adjust production volumes and schedules with minimal downtime, improving efficiency and flexibility. This capability ensures effective resource deployment, reducing costs while maintaining high productivity levels (Budianto et al., 2021). Agile systems align lean principles with adaptive capabilities, streamlining operations to meet customer expectations in dynamic environments. For instance, rapid response to demand fluctuations minimizes waste and enhances delivery reliability, key indicators of operations performance (Galankashi et al., 2019).

In Indonesia's manufacturing sector, agility is critical for navigating market volatility, infrastructural constraints, and competitive pressures. El-Khalil and Mezher (2020) emphasize that agility fosters resilience, enabling firms to maintain performance amidst disruptions like supply chain interruptions or economic shifts. The integration of Industry 4.0 technologies, such as IoT, automation, and AI-driven production systems, further enhances agility by enabling real-time adjustments to manufacturing processes (Hsu et al., 2022). These technologies allow firms to monitor market trends and customer demands closely, ensuring rapid adaptation to changing conditions (Nugroho et al., 2024). Additionally, agile manufacturing supports customization, enabling firms to meet diverse customer needs efficiently, which is particularly valuable in global markets. By combining flexibility with efficiency, agile systems ensure sustained operational excellence, aligning with strategic goals and enhancing competitiveness in volatile environments.

H5: Manufacturing agility has a positive impact on operations performance.

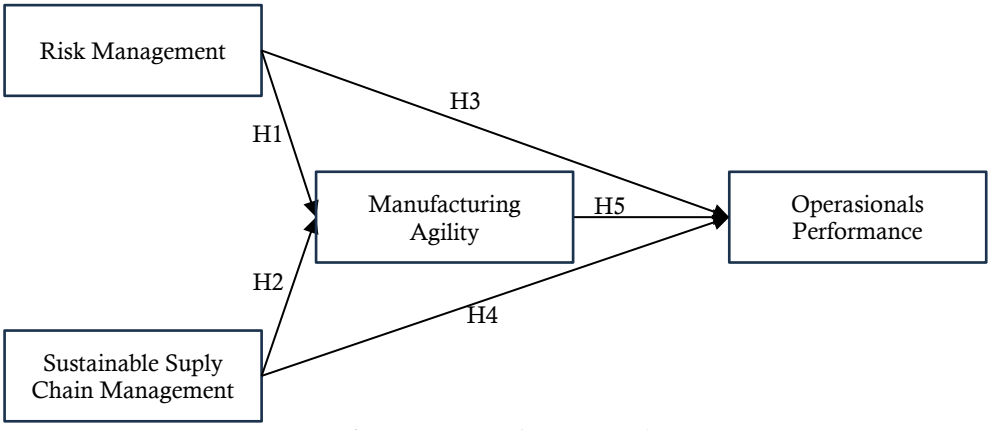

Figure 1. Research Framework

The relationships among risk management, sustainable supply chain management, manufacturing agility, and operations performance form the foundation of this study's theoretical framework. As illustrated in Figure 1, the research model proposes that risk management and sustainable supply chain practices positively influence manufacturing

agility, which in turn drives operations performance. Additionally, both risk management and sustainable practices directly impact operations performance, highlighting their multifaceted roles in supply chain success (Hsu et al., 2022). Figure 1 visually represents these hypothesized relationships, providing a clear framework for testing the interplay of these constructs in the context of Indonesia's manufacturing sector. This model integrates insights from prior studies, emphasizing the interconnected nature of agility, sustainability, and risk management in achieving operational excellence (Nugroho et al., 2024). By structuring the hypotheses within this framework, the study aims to provide empirical evidence for enhancing supply chain resilience and performance in developing economies.

RESEARCH METHOD

This study adopts a quantitative approach to investigate the interplay among sustainable supply chain practices, risk management, manufacturing agility, and operations performance within the Indonesian manufacturing sector. A structured questionnaire, utilizing a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), was employed to capture respondents' perceptions, ensuring standardized and measurable data collection. The target population included managers and executives in logistics, manufacturing, and supply chain roles, selected for their strategic insights into operational dynamics. The quantitative methodology facilitated robust statistical analysis, enabling the examination of hypothesized relationships with precision and reliability.

Data collection was conducted through an online survey to achieve broad geographic coverage, particularly within Indonesia's manufacturing hub, the Jabodetabek region, while also including respondents from other areas. The survey incorporated validated measurement items drawn from established literature to ensure construct reliability and validity. Specifically, items for risk management were adapted from Wiengarten et al. (2016), sustainable supply chain management from Zhang et al. (2022), manufacturing agility from Al-zabidi et al. (2021), and operations performance from Gligor et al. (2015). This approach ensured that the constructs were grounded in prior research, enhancing the study's theoretical rigor (Hair et al., 2019). The online survey method offered convenience for respondents, increasing participation rates and enabling efficient data collection across diverse organizational settings. A total of 255 valid responses were obtained from an initial 258 submissions, with three responses excluded due to incomplete answers, ensuring a robust sample for analysis.

The collected data were analyzed using SmartPLS, a structural equation modeling (SEM) tool well-suited for assessing complex relationships among latent variables in supply chain research. SmartPLS was chosen for its ability to handle non-normal data distributions and its robustness in testing theoretical models with multiple constructs (Hair et al., 2011). The analysis process involved evaluating the measurement model's reliability and validity through metrics such as Cronbach's Alpha, composite reliability, and Average Variance Extracted (AVE), followed by hypothesis testing via path coefficients and p-values. This approach allowed for a comprehensive examination of the proposed relationships, ensuring statistical rigor and alignment with the study's objectives.

RESULTS

This study's findings provide a comprehensive analysis of the relationships among risk management, sustainable supply chain practices, manufacturing agility, and operations performance in Indonesia's manufacturing sector. Data were collected from 255 valid responses out of 258 initial submissions, with three excluded due to incomplete answers, ensuring a robust dataset for analysis. The respondent pool, primarily managers and executives in logistics, manufacturing, and supply chain roles, offers valuable insights into operational dynamics. The demographic profile reveals a gender distribution of 58.7% male and 41.3% female, reflecting a balanced representation. Age-wise, 50.6% of

respondents are under 30, 20.3% are aged 31–40, 19.8% are 41–50, and 9.3% are over 50, indicating a diverse age range.

Most respondents (85.0%) work in the Jabodetabek region, Indonesia's manufacturing hub, while 15.0% are from other areas, ensuring geographic diversity. Professional experience varies, with 24.5% having over 10 years, 24.2% with 6–10 years, 26.9% with 3–5 years, and the rest newer to their roles. Company size distribution shows 35.1% in firms with over 5,000 employees, 25.3% in mid-sized firms (100–500 employees), 20.9% in firms with 501–1,000 employees, and 18.7% in smaller firms (<100 employees). Multinational corporations employ 63.0% of respondents, while 37.0% work in non-multinational firms, and 41.5% are in publicly listed companies versus 58.5% in privately owned ones. This diverse demographic profile, as summarized, provides a robust foundation for analyzing supply chain trends in Indonesia (Nugroho et al., 2024).

The outer loading analysis, conducted using SmartPLS, confirms the measurement model's robustness, with all indicators exceeding the threshold of 0.7, indicating strong reliability and validity (Hair et al., 2019). Notably, operations performance indicators demonstrate exceptional consistency, with outer loadings surpassing 0.87, reflecting high reliability for this construct. Other constructs, including risk management, sustainable supply chain management, and manufacturing agility, also exhibit consistent indicator reliability, reinforcing the model's strength. These findings align with prior research emphasizing the importance of reliable measurement models in supply chain studies (Wiengarten et al., 2016). The uniformity across constructs ensures that the indicators effectively capture the intended latent variables, providing a solid basis for subsequent structural analysis. This high level of indicator reliability is critical in the context of Indonesia's manufacturing sector, where complex operational dynamics require precise measurement to derive meaningful insights (Zhang et al., 2022).

Table 1. Reliability and Validity Analysis

Variable	Cronbach's a	rho_A	Composite Reliability	AVE
Risk Management	0.917	0.918	0.941	0.800
Sustainable Supply Chain Management	0.866	0.897	0.907	0.710
Manufacturing Agility	0.876	0.883	0.910	0.668
Operations Performance	0.880	0.880	0.926	0.806

Table 1 presents the reliability and validity analysis, offering detailed insights into the measurement model's robustness. As shown in Table 1, Cronbach's Alpha values range from 0.866 for sustainable supply chain management to 0.917 for risk management, all exceeding the recommended threshold of 0.7, confirming strong internal consistency (Hair et al., 2011). The rho_A values closely align with Cronbach's Alpha, further supporting construct stability across the dataset. Composite reliability scores, ranging from 0.907 to 0.941, surpass the 0.7 benchmark, indicating robust internal consistency for each construct. Additionally, AVE values, ranging from 0.668 for manufacturing agility to 0.806 for operations performance, exceed the 0.5 threshold, demonstrating substantial convergent validity. These metrics collectively validate the constructs' ability to measure their intended dimensions, providing a strong foundation for hypothesis testing. In the context of developing economies like Indonesia, such rigorous validation is essential to ensure the reliability of findings amidst unique operational challenges (Sánchez-Flores et al., 2020).

Table 2. HTMT analysis

Variable	Manufacturing Agility	Operations Performance	Risk Management
Operations Performance	0.743		
Risk Management	0.556	0.706	
SSCM	0.553	0.616	0.655

The Heterotrait-Monotrait Ratio (HTMT) analysis, presented in Table 2, confirms the discriminant validity of the constructs. As shown in Table 2, all HTMT values are below the 0.85 threshold, indicating that the constructs are distinct from one another (Hair et al., 2019). The highest HTMT value, 0.743, occurs between manufacturing agility and operations performance, while the lowest, 0.553, is between manufacturing agility and sustainable supply chain management. These results affirm the measurement model's ability to differentiate constructs, a critical aspect of structural equation modeling in supply chain research (Hsu et al., 2022). This clear distinction ensures that the relationships tested in the inner model are not confounded by overlapping constructs, enhancing the study's theoretical rigor. In Indonesia's manufacturing context, where operational constructs may share similarities due to integrated practices, this discriminant validity is particularly valuable (Men et al., 2023).

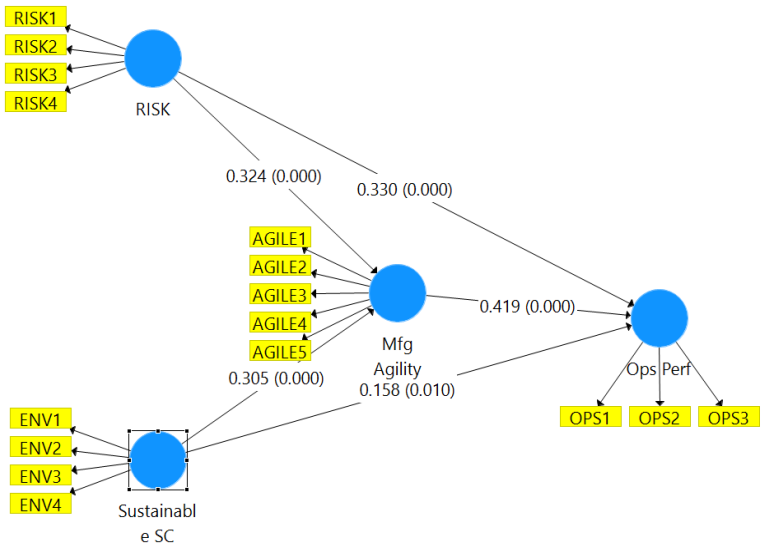

Figure 2. Path Coefficients and P-Values

Table 3. Hypothesis Testing Results

Hypothesis	Std. Dev	T Statistic	P Values
H1: Risk Management -> Manufacturing Agility	0.098	3.319	0.000
H2: Sustainable Supply Chain Management -> Manufacturing Agility	0.087	3.488	0.000
H3: Risk Management -> Operations Performance	0.081	4.078	0.000
H4: Sustainable Supply Chain Management > Operations Performance	0.067	2.341	0.010
H5: Manufacturing Agility > Operations Performance	0.067	6.250	0.000

The inner model evaluation, illustrated in Figure 2, presents the path coefficients and p-values for the hypothesized relationships. Figure 2 visually depicts the structural model, with path coefficients and p-values in parentheses, providing a clear overview of the relationships tested. Table 3 complements this by summarizing the hypothesis testing results, offering detailed statistical insights. As shown in Table 3, risk management significantly influences manufacturing agility (H1: $\beta = 0.324$, $p < 0.001$) and operations performance (H3: $\beta = 0.330$, $p < 0.001$), aligning with findings that proactive risk mitigation enhances flexibility and efficiency (Gurtu & Johny, 2021). Sustainable supply chain practices also positively impact manufacturing agility (H2: $\beta = 0.305$, $p < 0.001$) and operations performance (H4: $\beta = 0.158$, $p = 0.01$), though the effect on performance is weaker yet significant, consistent with studies emphasizing sustainability's multifaceted benefits (Golicic & Smith, 2013). Manufacturing agility demonstrates the strongest influence on operations performance (H5: $\beta = 0.419$, $p < 0.001$), underscoring its critical

role in dynamic environments (Abdelilah et al., 2021). These findings highlight the interconnected roles of risk management, sustainability, and agility in driving supply chain success in Indonesia.

The hypothesis testing results provide deeper insights into the relative strengths of these relationships, as reflected in the t-statistics reported in Table 3. The relationship between manufacturing agility and operations performance exhibits the highest t-statistic ($t = 6.250$, $p < 0.001$), indicating a robust and reliable impact, consistent with prior research emphasizing agility's role in dynamic markets (Arifin et al., 2018). Risk management's influence on manufacturing agility ($t = 3.319$, $p < 0.001$) and operations performance ($t = 4.078$, $p < 0.001$) underscores its importance in fostering resilience and efficiency (Braunscheidel & Suresh, 2009). Sustainable supply chain practices show a strong effect on agility ($t = 3.488$, $p < 0.001$) but a weaker, yet significant, effect on operations performance ($t = 2.341$, $p = 0.01$), suggesting indirect benefits through agility (Panigrahi et al., 2019). These results align with a systems-based perspective of supply chain management, where strategic investments in one area yield cascading benefits (Haq & Aslam, 2023). In Indonesia's manufacturing sector, these findings highlight the need for integrated strategies to enhance operational outcomes.

The results collectively affirm the proposed research model, as depicted in Figure 1, which illustrates the hypothesized relationships among the constructs. Figure 1 provides a visual framework for understanding how risk management and sustainable practices drive agility and performance, offering a clear roadmap for empirical analysis (Nugroho et al., 2024). The strong statistical support for all hypotheses (H1–H5) validates the model's applicability in Indonesia's context, where resource constraints and market volatility necessitate agile and resilient supply chains. The findings suggest that manufacturing agility is the most significant driver of operations performance, with risk management and sustainability acting as critical enablers. These insights contribute to the literature by providing empirical evidence from a developing economy, addressing gaps in prior research focused on developed regions (Inman & Green, 2021). For practitioners, the results emphasize the importance of prioritizing agility-enhancing initiatives, supported by robust risk management and sustainable practices, to achieve operational excellence in volatile markets.

DISCUSSION

The findings of this study illuminate the intricate relationships among risk management, sustainable supply chain practices, manufacturing agility, and operations performance in Indonesia's manufacturing sector, offering valuable insights into supply chain dynamics in a developing economy. The results confirm that risk management significantly enhances manufacturing agility (H1: $\beta = 0.324$, $p < 0.001$) and operations performance (H3: $\beta = 0.330$, $p < 0.001$), aligning with Gurtu and Johny's (2021) assertion that proactive risk mitigation fosters resilience and efficiency. By implementing real-time monitoring and contingency planning, firms can navigate disruptions, such as supply chain interruptions or regulatory shifts, which are prevalent in Indonesia's resource-constrained environment. This capability is critical for maintaining operational continuity, particularly in volatile markets where infrastructural limitations amplify risks (Wiengarten et al., 2016). Similarly, sustainable supply chain practices positively influence manufacturing agility (H2: $\beta = 0.305$, $p < 0.001$) and, to a lesser extent, operations performance (H4: $\beta = 0.158$, $p = 0.01$). According to Golicic and Smith (2013), sustainability initiatives, such as recycling and resource optimization, drive innovation and flexibility, enabling firms to adapt to supply shortages and environmental regulations. These findings underscore the strategic value of integrating sustainable practices to enhance agility, particularly in Indonesia, where regulatory pressures and resource scarcity necessitate innovative approaches (Sánchez-Flores et al., 2020).

The most pronounced relationship in this study is between manufacturing agility and operations performance (H5: $\beta = 0.419$, $p < 0.001$), with the highest t-statistic ($t = 6.250$), reinforcing Abdelilah et al.'s (2021) view that agility is a critical driver of operational

excellence in dynamic environments. Agile manufacturing systems allow firms to adjust production processes swiftly, minimizing downtime and optimizing resource use, which is vital in Indonesia's competitive manufacturing landscape. This finding aligns with prior research emphasizing agility's role in responding to market fluctuations and customer demands, thereby enhancing efficiency and delivery reliability (Arifin et al., 2018). The weaker direct effect of sustainable practices on operations performance suggests that their impact is mediated through agility, a notion supported by Panigrahi et al. (2019), who argue that sustainability drives performance indirectly by fostering system-wide efficiencies. In Indonesia, where the manufacturing sector faces global competition and local constraints, this interplay highlights the need for integrated strategies that combine sustainability, risk management, and agility to achieve operational success (Nugroho et al., 2024).

The interconnected nature of these constructs supports a systems-based perspective of supply chain management, as noted by Haq and Aslam (2023), where strategic investments in one area yield cascading benefits across others. For instance, risk management enhances agility by mitigating disruptions, while sustainable practices foster innovation, enabling firms to remain adaptable and competitive. These findings fill critical research gaps by providing empirical evidence from a developing economy, addressing Inman and Green's (2021) call for studies in resource-constrained contexts. The results also highlight the pivotal role of agility as a mediator, amplifying the effects of risk management and sustainability on performance outcomes. This is particularly relevant in Indonesia, where the manufacturing sector, a key economic driver, must navigate volatile markets and infrastructural challenges (Zhang et al., 2022).

Theoretically, this study advances supply chain management literature by demonstrating the integrated effects of risk management, sustainability, and agility in a developing economy, contributing to resilience frameworks. Practically, it offers actionable insights for Indonesian manufacturers and policymakers, emphasizing the need to prioritize agility-enhancing technologies, such as IoT and automation, while integrating robust risk management and sustainable practices (Hsu et al., 2022). Firms should invest in flexible production systems and green technologies to enhance competitiveness, while policymakers can support these efforts through incentives for sustainable practices and infrastructure development.

CONCLUSION

This study provides significant insights into the interplay of risk management, sustainable supply chain practices, manufacturing agility, and operations performance within Indonesia's manufacturing sector, contributing to the discourse on supply chain resilience in developing economies. The findings confirm that manufacturing agility exerts the strongest influence on operations performance ($\beta = 0.419$, $t = 6.250$, $p < 0.001$), highlighting its pivotal role in enabling firms to adapt to dynamic market conditions and optimize resource utilization. Risk management positively impacts both agility ($\beta = 0.324$, $p < 0.001$) and operations performance ($\beta = 0.330$, $p < 0.001$), underscoring its role in fostering resilience and efficiency. Sustainable supply chain practices enhance agility ($\beta = 0.305$, $p < 0.001$) and, to a lesser extent, operations performance ($\beta = 0.158$, $p = 0.01$), suggesting indirect benefits through agility. These results align with a systems-based perspective, where integrated strategies amplify supply chain success in volatile environments. The robust statistical support for all hypotheses validates the research model's applicability in Indonesia, addressing gaps in prior studies focused on developed regions.

The theoretical contribution of this study lies in its empirical validation of an integrated framework linking risk management, sustainability, and agility in a developing economy, advancing supply chain resilience literature. Practically, the findings suggest that Indonesian manufacturers should prioritize agility-enhancing technologies, such as IoT and automation, while integrating robust risk management and sustainable practices to achieve operational excellence. Policymakers can support these efforts through incentives

for green technologies and infrastructure improvements. However, the study's limitations include its focus on Indonesia and reliance on cross-sectional data, which may limit generalizability and insights into temporal dynamics. Future research should explore these relationships in broader geographic contexts and employ longitudinal designs to capture causal dynamics.

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