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Development of a Initialization and Supply Chain Resilience Model to Enhance Operational Performance in The Software Development Industry

Muhammad Mahdi[1*], Jonny [2]

[1] Industrial Engineering Department, BINUS Graduate Program – Master of Industrial Engineering, University Bina Nusantara, Jakarta, Indonesia

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Corresponding Author:
Muhammad Mahdi
muhammad.mahdi003@binus.ac.id

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Abstract: As an effort to enhance competitiveness and operational efficiency, it is essential for software development companies to continuously monitor and evaluate the operational performance of their supply chains. In the era of Industry 4.0, digitalization is imperative because the rapidly changing market dynamics can create vulnerabilities in the supply chain, making it necessary to strengthen the supply chain resilience of an industry. This research aims to develop a Model of Digitalization and Supply chain Resilience in the Software Development Industry and to test the variables that influence the operational performance of the supply chain. Data in this study is collected through questionnaires addressed to operational managers specifically in the field of supply chain. The data will be tested using Structural Equation Modeling with the help of SMART-PLS software. It is hoped that the results of this research can serve as a reference and recommendation for academics and practitioners regarding the model of digitalization and supply chain resilience in the software development industry.

Keywords: Development; Digitalization; Resilience; Software; Supply chain.

Introduction

Technology companies, particularly software developers, have complex supply chains involving various stages, from procurement, production processes, and distribution to delivery to the end consumer (Lwakatare et al., 2019; Sukmawati et al., 2022). In the context of the software supply chain, multiple components are involved, including code, configurations, proprietary and open-source binaries, libraries, plugins, and container dependencies . It also includes tool creators such as assemblers, compilers, code analyzers and repositories, security, monitoring, and logging operation tools (Hizam-Hanafiah & Soomro, 2021). The software supply chain also encompasses the people, organizations, and processes involved in software development (Soomro et al., 2021).

As an effort to enhance competitiveness and operational efficiency, it is crucial for software development companies to continuously monitor and evaluate the operational performance of their supply chain (Dzikriansyah et al., 2023; Sukmawati et al., 2022). Supply chain management in a company refers to managing and coordinating the flow of products and information from upstream producers to consumers in need of services (Han & Li, 2025). In software companies, supply chain management is essential to ensure a smooth supply of various software products to satisfy customers (Han & Li, 2025). Supply chains in the technology sector often face constantly changing complexities, particularly in managing the demand for software products with short lifecycles and highly fluctuating demand (Riswanto et al., 2023).

The software supply chain faces several issues, including vulnerabilities in infrastructure, software, codebases, people, and processes. Infrastructure, such as servers and network devices, is prone to misconfiguration, which can exacerbate vulnerabilities to cyberattacks (Insiders, 2019). Software, whether proprietary or open-source, can be vulnerable to malicious code insertion or bug exploitation, as well as issues like package dependency confusion and update

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hijacking (Insiders, 2019). Codebases, which house these programs, are also vulnerable, with most commercial codebases using open-source software containing outdated components. Additionally, issues may arise from people within the supply chain, whether intentionally or unintentionally (Librantz et al., 2021; Martínez & Durán, 2021). Finally, the processes within the supply chain, especially identity and access management (IAM), are attractive targets for attackers to introduce spyware and ransomware (Insiders, 2019). Thus, the software supply chain comes with various risks involving technology, people, and processes, all of which can be exploited by criminals to infiltrate it.

Technological advancements in supply chains, also known as Supply Chain 4.0 (SC4.0), have increased seamless interconnections in globalized supply chains, leading to enhanced operational effectiveness and efficiency (Han & Li, 2025; Maretalinia et al., 2023). The Fourth Industrial Revolution has transitioned from traditional supply chains to digital supply chains to support new production models, transportation modes, customer experiences, and supply chains. The implementation of digital supply chains is influenced by the development status of countries, which is especially evident in developing countries. Traditional supply chains, particularly in developing countries, have not yet been able to quickly adapt to the breakthrough innovations brought about by the technological advances of Industry 4.0 (Fonna, 2019).

Digitalization has become a buzzword in industries over the past decade. The influence and scope of digitalization in the industry continue to increase (Aksenta et al., 2023). Digitalization in the supply chain involves the application of digital technology to plan and execute transactions, communication, and actions (Hegazy et al., 2023). Nearly 90% of companies believe that digitalization will provide a competitive advantage in the supply chain over the next five years; however, most respondents (73%) are highly unclear about what "supply chain digitalization" means (Widowati et al., 2023). Companies that are unprepared to keep pace with these digital and technological advancements may fall behind and ultimately go bankrupt (Saputra et al., 2021). Based on this explanation, this study aims to resilience of the supply chain in mediating supply chain digitalization toward operational performance in software development companies.

Method

This research employs a descriptive quantitative approach to examine the relationship between independent and dependent variables, such as supply chain digitalization, supply chain survivability, and company operational performance (Sugiyono, 2019). Data were collected through a questionnaire distributed to 100 software development companies in Indonesia. A purposive sampling technique was used to ensure that the selected respondents were operational managers or individuals with a deep understanding of the company's supply chain. The data collection process involved the use of a Likert scale to measure respondents' perceptions, and the data analysis was conducted using SMART-PLS version 4 software. Validity and reliability tests were performed to ensure the accuracy and reliability of the research instrument.

The research results were analyzed using both the measurement model (outer model) and the structural model (inner model) to evaluate the relationships between variables. The validity and reliability of the indicators were assessed using methods such as Average Variance Extracted (AVE) and Cronbach's Alpha. This study aims to provide insights into how supply chain digitalization and supply chain survivability can enhance the operational performance of software development companies in Indonesia.

Result and Discussion

Overview of the Supply Chain in Software Development Companies

The supply chain in software development companies differs significantly from traditional supply chains that focus on physical goods. Software products are digital and complex, influenced by rapid technological advancements and dynamic market demands (Librantz et al., 2021; Martínez & Durán, 2021). According to (Wamba et al., 2019), the software supply chain involves several key elements, such as technology suppliers, development teams, testing, project management, product distribution, and after-sales services. Each element works cohesively to ensure that software products are developed, tested, distributed, and maintained effectively.

Technology Suppliers play a crucial role in providing hardware, third-party software, cloud platforms, and development tools. The development team then leverages this technology to design and build software that meets market needs. Testing is a critical stage that ensures the quality of the software before release, focusing on functional, security, and performance testing. Project management coordinates the entire development process, ensuring it stays on schedule and within the allocated resources. Once the software is ready, product distribution is carried out digitally through online platforms, ensuring fast and easy access for end users. After the launch, after-sales services such as technical support and software updates are essential for maintaining long-term customer satisfaction.

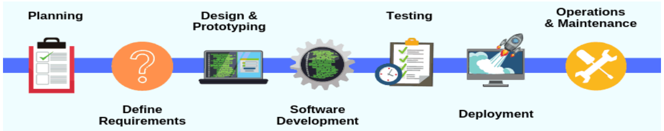

Figure 1. Software Development Life Cycle (SDLC)

In addition to these elements, the software supply chain is also influenced by the Software Development Life Cycle (SDLC). SDLC is a structured method that encompasses various phases in software development, from planning to maintenance. There are seven main phases in SDLC: planning, requirement gathering, design, development, testing, deployment, and maintenance.

The planning phase is the initial step where project goals are set, resources are allocated, and risks are identified. Following this, the team gathers and documents the software's requirements, including both functional and non-functional needs. During the design phase, the software architecture is created, and initial prototypes are developed for feedback. Development is carried out based on the agreed-upon design, with the development team working in parallel to complete various software components. Once coding is finished, the testing phase ensures the software functions as specified and is free of bugs.

The deployment phase involves launching the software into a production environment, ensuring it operates optimally in users' systems. After deployment, the final phase is operations and maintenance, where the software is maintained to fix bugs and update features based on user needs. Implementing SDLC in the software supply chain ensures that each component of the development and distribution process is well-managed, from concept to product launch and maintenance. SDLC helps mitigate errors and improves efficiency, especially amid the complexity of modern software supply chains that involve multiple digital elements. Despite its challenges, the software supply chain presents significant opportunities through the application of big data analytics and emerging technologies like artificial intelligence (AI). Big data enables better visibility into the supply chain and supports faster and more accurate decision-making, while AI and the Internet of Things (IoT) facilitate improved integration between supply chain components.

Thus, although complex and challenging, the supply chain of software development companies holds great potential for growth through the appropriate utilization of technology and innovation.

SEM-PLS Analysis

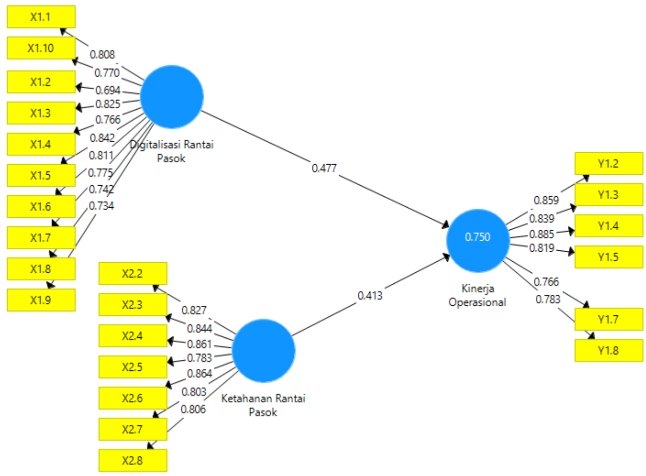

Figure 2. Output of the Outer Model After Invalid Indicators Were Removed

Construct Validity

After removing indicators such as X11, X12, X13, X14, X2.1, Y1.1, and Y1.6, which did not meet the convergent validity requirements, there was an improvement in the outer loading values, indicating a stronger relationship between the latent variables and their indicators. Overall, the results of the Outer Model, after removing the invalid indicators, show an improvement in construct validity. All remaining indicators now have adequate outer loading values that meet convergent validity criteria, indicating that the constructs are accurately measured by the remaining indicators.

Discriminant Validity

Results of Discriminant Validity Analysis from the Three Main Constructs: Supply Chain Digitalization, Supply Chain Resilience, and Operational Performance. Discriminant validity was evaluated using several measures, including Cronbach’s Alpha, rho_A, Composite Reliability, and Average Variance Extracted (AVE). Overall, the results of the discriminant validity analysis, after removing invalid indicators, show that all the main constructs in this model have high reliability and good convergent validity. This indicates that the constructs are consistently and accurately measured by the remaining indicators, which are essential elements in the validity of the measurement model.

Table 1. Discriminant Validity Output

Parameters	Cronbach's Alpha	rho_A	Composite reliability	Average Variance Extracted (AVE)
Supply Chain Digitalization	0.927	0.930	0.939	0.605
Supply Chain Resilience	0.923	0.924	0.938	0.684
Operational Performance	0.907	0.913	0.928	0.682

Collinearity testing

Collinearity testing was conducted to ensure that there were no significant multicollinearity issues among the indicators in the model. Multicollinearity can distort parameter estimates in the model, thereby reducing the accuracy and interpretability of the analysis results.

Table 2. Variance Inflation Factor

Class	VIF
X1.1	2.998
X1.10	2.337
X1.2	1.901
X1.3	3.106
X1.4	2.312
X1.5	3.738
X1.6	3.148
X1.7	2.715
X1.8	2.035
X1.9	2.083
X2.2	2.661
X2.3	3.413
X2.4	3.169
X2.5	2.166
X2.6	3.748
X2.7	2.167
X2.8	2.284
Y1.2	3.441
Y1.3	2.791
Y1.4	3.190
Y1.5	2.789
Y1.7	2.487
Y1.8	2.213

The results of the collinearity test, presented through the Variance Inflation Factor (VIF) values, show that all indicators have VIF values below the common threshold of 5, indicating no serious multicollinearity issues. VIF values lower than 5 suggest that there is no excessive correlation between the indicators, so no indicators need to be removed or modified.

Overall, these collinearity test results indicate that the model is free from significant multicollinearity problems, meaning that the parameter estimates in this model can be considered reliable and valid. This supports the quality of the measurement model used in this research.

Reliability

Reliability testing was conducted to measure the internal consistency of the indicators used to assess the constructs in the research model. Three main measures were used to evaluate reliability: Cronbach's Alpha, rho_A, and Composite Reliability.

Table 3. Reliability Test Output

Parameters	*Cronbach's Alpha*	rho_A	*Composite reliability*
Supply Chain Digitalization	0.927	0.930	0.939
Supply Chain Resilience	0.923	0.924	0.938
Operational Performance	0.907	0.913	0,928

The reliability test results for the three main constructs—Supply Chain Digitalization, Supply Chain Resilience, and Operational Performance—show that all constructs have excellent reliability. The Supply Chain Digitalization construct has a Cronbach's Alpha of 0.927, rho_A of 0.930, and Composite Reliability of 0.939. These values indicate that the indicators measuring Supply Chain Digitalization have very high internal consistency, meaning that the indicators consistently measure the same concept.

Overall, these reliability test results demonstrate that all three constructs in this model have very high internal consistency, which means that the data obtained from these indicators are reliable and valid for further analysis. With such high reliability, this model can be used to draw accurate and dependable conclusions regarding the relationships between the measured constructs.

R-Square

The R Square test was conducted to evaluate how well the constructed model explains the variability of the dependent variable, in this case, Operational Performance. R Square and Adjusted R Square values are used as the main indicators to assess the strength of the model.

Tabel 4. R-Square Output

Parameter	R Square	R Square Adjusted
Operational Performance	0.750	0.745

The test results show that the R Square value for the Operational Performance construct is 0.750. This means that 75% of the variability in Operational Performance can be explained by the independent variables in the model, namely Supply Chain Digitalization and Supply Chain Resilience. This high R Square value indicates that the model has an excellent ability to explain changes in Operational Performance based on the variables used.

The Adjusted R Square value of 0.745 is slightly lower than the R Square value, which accounts for the number of predictors in the model. This adjustment is important to avoid overfitting, where the model appears to perform well on the sample data but may not generalize well to a broader population. The fact that the Adjusted R Square value is only slightly lower than the R Square value indicates that the model remains stable and not overly complex, even when considering the number of variables used.

Overall, the obtained R Square and Adjusted R Square values indicate that the model has strong predictive power, with the majority of variability in Operational Performance explained by the variables in the model. This shows that the model is a good representation of the relationships between the measured variables and can be reliably used to draw conclusions about how Supply Chain Digitalization and Supply Chain Resilience influence Operational Performance.

Coefficients was conducted to determine the strength and significance of the relationships between the independent variables and the dependent variable in the research model. In the presented table, two main relationships are evaluated: the relationship between Supply Chain Digitalization and Operational Performance, and the relationship between Supply Chain Resilience and Operational Performance.

Table 5. Path Coeffisient Output

Parameters	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Supply Chain Digitalization -> Operational Performance	0.477	0.472	0.113	4.236	0.000
Supply Chain Resilience -> Operational Performance	0.413	0.421	0.113	3.661	0.000

Supply Chain Digitalization has a path coefficient of 0.477, with a T-statistic value of 4.236 and a P-value of 0.000 < 0.05. This path coefficient indicates that Supply Chain Digitalization has a significant positive impact on Operational Performance. The P-value, which is far below the 0.05 threshold, suggests that this effect is statistically significant, and thus the hypothesis that Supply Chain Digitalization positively influences Operational Performance can be accepted.

Similarly, Supply Chain Resilience shows a path coefficient of 0.413, with a T-statistic value of 3.661 and a P-value of 0.000 < 0.05. This also indicates a significant positive impact of Supply Chain Resilience on Operational Performance. Given the P-value is also well below 0.05, the hypothesis that Supply Chain Resilience has a significant positive effect on Operational Performance can be accepted.

Overall, the results of this hypothesis test show that both independent variables, Supply Chain Digitalization and Supply Chain Resilience, significantly and positively influence Operational Performance. This strong and significant influence highlights the importance of digitalization and resilience in enhancing a company's operational performance. These two factors are key elements in creating more efficient, responsive, and competitive operations in a dynamic business environment.

Goodness of Fit

Goodness of fit is a measure used to evaluate how well a statistical model matches the observed data.

Table 6. *Goodness of Fit*

Parameters	Saturated Model	Estimated Model
SRMR	0.059	0.059
d_ULS	1.706	1.706
d_G	1.703	1.703
Chi-Square	754.960	754.960
NFI	0.982	0.982

In the provided table, several indicators are used to assess the model's goodness of fit, including SRMR (Standardized Root Mean Square Residual), d_ULS, d_G, Chi-Square, and NFI (Normed Fit Index). The SRMR value of 0.059 indicates a relatively small average difference between the observed and predicted covariance matrices, with this value being below the 0.08 threshold, which is generally accepted as an indication of good fit. This means the model represents the data well.

The d_ULS and d_G values, at 1.706 and 1.703 respectively, also indicate good alignment between the data and the model, although these measures do not have specific cutoff points in fit assessment. The Chi-Square value of 754.960 is also generated, but this statistic is highly sensitive to sample size, so in models with large samples, a significant Chi-Square value does not necessarily indicate poor fit.

The NFI (Normed Fit Index) in this model has a value of 0.982, which is close to the perfect score of 1.0 and well above the 0.90 threshold. This suggests that the model has an excellent level of fit and very accurately reflects the data structure. Overall, these goodness of fit values indicate that the model has a very good fit and can be considered robust or stable in representing the data. None of the indicators suggest any issues with the model's fit to the data, so this model can be considered stable and reliable for the structural analysis conducted.

The Relationship Between Supply Chain Digitalization and Operational Performance

The SEM-PLS analysis results show that supply chain digitalization has a significant and positive impact on operational performance, with a path coefficient of 0.477 and a T-statistic value of 4.236, both indicating high significance ($P < 0.001$). This suggests that the higher the level of digitalization in the supply chain, the better the operational performance that can be achieved by the company. These findings align with previous research emphasizing the importance of digitalization in achieving operational efficiency and competitive advantage.

According to Bai et al. (2020), supply chain digitalization strengthens the overall integration of supply chain processes, from procurement and production to distribution, by enhancing real-time information sharing and data transparency across the supply chain. The study also shows that digitalization can reduce operational costs by eliminating inefficiencies and accelerating decision-making processes, ultimately improving operational performance.

Fatorachian & Kazemi (2021) emphasize that supply chain digitalization enables companies to be more responsive to market changes, improve product quality, and accelerate the development of new products. Through digitalization, data from various supply chain systems and platforms can be efficiently integrated and analyzed, allowing companies to identify performance improvement opportunities and innovate products more quickly. The study found that digitalization has a significant positive impact on operational performance, particularly in terms of reducing production cycle time and improving product quality.

Holmström Jan (2017) also highlight the important role of digitalization in extending product life cycles and achieving sustainable performance improvements. They argue that digitalization, through digital procurement, digital production, and digital logistics, helps companies achieve operational excellence by reducing dependence on manual processes and increasing speed and accuracy in the supply chain.

The Relationship Between Supply Chain Resilience and Operational Performance

The SEM-PLS analysis results show that supply chain resilience has a significant and positive impact on operational performance, with a path coefficient of 0.413 and a T-statistic value of 3.661, both indicating high significance ($P < 0.001$). This indicates that improving supply chain resilience directly contributes to the enhancement of a company's operational performance. These findings are consistent with various previous studies that stress the importance of supply chain resilience in maintaining stable and sustainable operational performance, especially in uncertain situations.

Research by Ponomarov & Holcomb (2009) revealed that supply chain resilience is a key capability that enables companies not only to survive disruptions but also to recover quickly and seize opportunities that arise post-disruption. They emphasize that companies with high supply chain resilience tend to have better operational performance because they can mitigate risks more effectively and maintain operational continuity despite disruptions.

Additionally, research by Ghazinoory et al. (2011) shows that one of the main aspects of supply chain resilience is absorptive capacity, which includes the ability to absorb the impact of disruptions while maintaining efficient operations. This ability helps companies reduce volatility and uncertainty associated with disruptions, which in turn helps maintain high operational performance.

Theoretical Implications

This research makes significant contributions to the development of theory in the context of supply chain management, particularly in the software development industry, which is increasingly influenced by digital technology and the need for operational resilience. The finding that supply chain digitalization has a positive and significant impact on operational performance in this industry supports theories emphasizing the importance of technology integration in software supply chains to enhance operational efficiency and responsiveness. In the software development industry, the adoption of digital technologies such as DevOps, cloud computing, and workflow automation has been proven to accelerate development cycles and improve overall product quality (Hoda et al., 2012).

This research also reinforces the theory that digitalization in software development is not only about integrating new technologies but also involves transforming business processes and workplace culture within the company. Effective digitalization enables software developers to be more responsive to changing market demands and to accelerate the software development and testing process, which ultimately significantly improves operational performance (Liu et al., 2020).

Furthermore, the finding that supply chain resilience has a significant impact on operational performance in the software development industry affirms the relevance of resilience theory in a technology context. Software supply chain resilience includes a company's ability to address disruptions such as cyberattacks, regulatory changes, or cloud service outages. In this regard, absorptive, responsive, and recovery capabilities are critical for software development companies to maintain the continuity of their services and product quality (Hohenstein et al., 2015).

Additionally, these theoretical implications suggest that supply chain resilience in the software development industry should be viewed as interrelated with digitalization. The research indicates that the adoption of technologies such as AI for automated testing, blockchain for digital identity management, and big data for predictive analytics not only enhances operational efficiency but also strengthens a company's ability to respond to and recover from disruptions (Kipper et al., 2021). This reinforces the view that in the context of software development, digitalization and resilience are two sides of the same coin, both playing crucial roles in ensuring the continuity and success of a company's operations.

The theoretical implications of these findings also suggest that the software development industry should develop more flexible and adaptive business models that integrate digital technologies with resilience strategies. Existing theories can be expanded by exploring how the interaction between digital technologies and resilience can be optimized to achieve sustainable competitive advantage. Future research could explore the application of these concepts in software development companies of varying sizes, from startups to multinational corporations, as well as in different geographic contexts (Hoda et al., 2012).

Overall, this research enriches our understanding of the relationship between digitalization, resilience, and operational performance in the software development industry and encourages the development of new theories more relevant to the unique challenges faced by companies in this industry. As a result, this research opens opportunities for further studies that can inform best practices in software supply chain management in the future.

Practical Implications

This research provides several important practical implications for companies, particularly in the software development industry, that aim to improve their operational performance through supply chain digitalization and enhanced supply chain resilience. First, the finding that supply chain digitalization significantly impacts operational performance highlights the importance of investing in digital technology. Software development companies should consider adopting technologies such as DevOps for software development automation, cloud service management, and big data analytics to accelerate development cycles and improve operational efficiency (Li et al., 2020). By integrating these technologies, companies can increase transparency, collaboration, and responsiveness in their supply chains, which ultimately enhances operational performance.

Second, the research findings also indicate that supply chain resilience significantly affects operational performance. This provides practical insight into the need for companies to develop strong and flexible risk management strategies to address potential disruptions, such as technological failures or regulatory changes (Ivanov & Dolgui, 2020). To enhance resilience, companies can implement redundancies in their supply chains, such as using multiple cloud service providers or maintaining data backups in various geographic locations. These measures can help companies minimize risks and accelerate operational recovery after disruptions.

Additionally, it is important for companies to build an organizational culture that supports digitalization and resilience. This can be achieved through continuous training for employees in the use of digital technologies and in implementing emergency response procedures. By building awareness and capability across the organization, companies can ensure that all employees are prepared to adapt to rapid changes and respond effectively to disruptions (Kipper et al., 2021).

Another practical recommendation from this research is to improve collaboration between companies and their supply chain partners. Software development companies should adopt digital collaboration platforms that enable real-time information sharing with suppliers, distributors, and customers. This not only enhances operational efficiency but also strengthens trust and engagement in the supply chain, which is crucial for maintaining stable performance amid uncertainty (Hoda et al., 2012).

In an increasingly interconnected global context, companies must also consider the impact of international regulations and data security. The implementation of digital technology in supply chains must take into account compliance with data privacy regulations and international security standards. By adhering to these regulations, companies can reduce legal risks and maintain customer trust, which is essential for long-term sustainability (Liu & Chiu, 2021).

Overall, this research provides practical guidance for software development companies to improve their operational performance through the adoption of digital technologies and the strengthening of supply chain resilience. By applying these findings, companies can better prepare for future challenges and capitalize on opportunities for growth in a dynamic business environment.

Conclusion

Supply chain digitalization and resilience have a significant impact on improving operational performance in the software development industry. Developing an effective supply chain digitalization model requires integrating technologies such as DevOps, cloud computing, and big data analytics to provide flexibility and adaptability in responding to dynamic market changes. Key variables contributing to this model include digital technology, risk management, operational flexibility, supply chain collaboration, and digital culture. Digital technology has been proven to accelerate software development cycles and improve product quality, while risk management plays a crucial role in identifying and mitigating potential disruptions. Operational flexibility allows companies to quickly adapt to changing market demands, while supply chain collaboration ensures efficient communication and coordination among all parties involved. Additionally, digital culture strengthens the adoption of new technologies and drives innovation. Overall, digitalization accelerates development and improves product quality, while supply chain resilience ensures operational continuity and recovery from disruptions, ultimately contributing to increased operational efficiency and customer satisfaction. To further enhance operational performance, software development companies are advised to continue investing in digital technologies such as DevOps, cloud computing, and big data analytics, which will accelerate development cycles and improve transparency and collaboration in the supply chain. Strengthening supply chain resilience through strategies focused on absorptive, responsive, and recovery capabilities, including resource diversification and the use of predictive technologies for risk management, is also critical. Additionally, close collaboration with supply chain partners through digital platforms can improve efficiency, while regular training to strengthen digital culture within the company will ensure employees effectively utilize new technologies. Companies must also adhere to data privacy and security regulations and implement continuous monitoring and evaluation systems. Future research can focus on measuring the long-term impact of digital technology adoption on supply chain resilience and exploring factors that influence the adoption of new technologies in the context of the software industry

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