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The Implementation Of The Internet Of Things (IOT) In Smart Warehouse For Optimizing Supply Chain Performance In Mining Company

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Abstract

The adoption of digital technologies has accelerated supply chain transformation, particularly through the implementation of the Internet of Things (IoT) in smart warehouse systems. This study examines the effect of IoT implementation on supply chain performance in mining companies, with Smart Warehouse acting as a mediating variable. Data were collected from 100 respondents involved in logistics and warehouse operations and analyzed using Partial Least Squares - Structural Equation Modeling (PLS-SEM). The results indicate that IoT has a significant direct effect on supply chain performance and a strong positive effect on Smart Warehouse implementation. Furthermore, Smart Warehouse significantly enhances supply chain performance and partially mediates the relationship between IoT and supply chain performance. From a practical perspective, the findings highlight the importance for mining companies to prioritize IoT-enabled warehouse digitalization to improve inventory accuracy, distribution speed, and operational efficiency in geographically complex and capital-intensive environments. However, this study is limited by its cross-sectional design, reliance on perceptual data, and a sample restricted to mining companies, which may limit generalizability. Future research is encouraged to incorporate longitudinal data, objective performance indicators, and comparative industry analyses to strengthen the robustness of digital supply chain insights.

Keywords : Internet of Things, Smart Warehouse, Supply Chain Performance, Mining Industry

1. Introduction

Digital transformation has become a critical driver of supply chain efficiency across industries, particularly through the adoption of the Internet of Things (IoT), automation, and real-time data integration. IoT enables organizations to enhance operational visibility, reduce manual errors, and improve coordination across logistics activities. In warehouse management, IoT-based systems commonly referred to as smart warehouses allow real-time inventory monitoring, automated material handling, and faster decision making, thereby supporting overall supply chain performance.

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The mining industry presents a unique supply chain context due to its large material volumes, geographically dispersed operations, and dependence on timely availability of critical spare parts and raw materials. Inefficient warehouse management in mining operations often results in inventory inaccuracies, distribution delays, and increased operational costs, which can disrupt production continuity. Despite these challenges, many mining companies continue to rely on conventional, manual-based warehouse systems that limit transparency and responsiveness.

The implementation of IoT in smart warehouses offers a strategic solution to these challenges. Through technologies such as sensors, RFID, and real-time tracking systems, mining companies can improve inventory accuracy, reduce lead times, and enhance coordination between warehouses and operational sites. Prior studies have demonstrated that IoT adoption improves supply chain visibility and efficiency in manufacturing and general logistics contexts. However, empirical evidence focusing on IoT-enabled smart warehouses within the mining industry particularly in emerging economies such as Indonesia remains limited.

Moreover, existing research often examines IoT adoption and supply chain performance independently, without explicitly considering the mediating role of smart warehouses. This creates a gap in understanding how IoT capabilities are operationalized at the warehouse level and translated into measurable supply chain performance outcomes in complex industrial settings.

To address this gap, this study investigates the effect of IoT implementation on supply chain performance in mining companies, with Smart Warehouse functioning as a mediating variable. Using a quantitative approach and PLS-SEM analysis, this research aims to provide empirical insights into the role of warehouse digitalization in strengthening supply chain performance. The findings are expected to contribute both theoretically by integrating IoT and smart warehouse perspectives within supply chain management—and practically, by offering guidance for mining firms in designing effective digital transformation strategies.

2. Literature Review

2.1 *Internet of Things (IoT) and Supply Chain Performance*

The Internet of Things (IoT) has been widely recognized as a foundational technology enabling digital transformation in supply chain management. Prior studies emphasize IoT's ability to enhance real-time visibility, data accuracy, and inter-organizational coordination through connected sensors, RFID, and automated monitoring systems (Porter & Heppelmann, 2019; Ben-Daya et al., 2019). From this perspective, IoT functions as an enabler of faster decision-making and improved responsiveness, which are key dimensions of supply chain performance.

However, empirical findings reveal that the performance impact of IoT is not always direct. While some studies report significant improvements in cost efficiency and delivery reliability following IoT adoption (Ivanov et al., 2019), others argue that technology alone does not automatically translate into performance gains without complementary organizational and process-level integration (Lee & Lee, 2015). This divergence suggests that IoT's effectiveness depends on how deeply it is embedded within operational systems, particularly warehouse management processes that act as critical nodes in the supply chain.

In the mining industry, where material flows are complex and geographically dispersed, IoT adoption has the potential to reduce uncertainty in inventory availability and material movement. Nevertheless, empirical research in this sector remains scarce and largely descriptive, offering limited insight into the mechanisms through which IoT improves performance outcomes. Based on this synthesis, this study posits that IoT implementation positively influences supply chain performance, either directly or through operational integration mechanisms.

2.2 *Internet of Things (IoT) and Smart Warehouse*

Smart warehouses represent an operational manifestation of IoT within logistics systems. Previous studies describe smart warehouses as environments where IoT devices, automation technologies, and data analytics are integrated to improve inventory accuracy, reduce lead times, and enhance process efficiency (Baruffaldi et al., 2019; Kusuma et al., 2020). These studies suggest that IoT serves as the technological backbone enabling warehouse digitalization.

Despite broad agreement on this relationship, the literature reveals varying levels of maturity in smart warehouse adoption. Some scholars emphasize the transformative role of IoT in enabling fully automated and data-driven warehouses (Gunasekaran et al., 2017), while others highlight persistent barriers such as high investment costs, cybersecurity risks, and resistance to organizational change (Lee & Lee, 2015; Wang & Xu, 2022). This tension indicates that IoT adoption alone is insufficient unless it is effectively translated into warehouse-level capabilities.

In the context of mining operations, warehouses play a strategic role in ensuring the availability of spare parts and production materials. IoT-enabled smart warehouses can significantly reduce manual handling errors and improve material traceability, which are critical for maintaining operational continuity. Building on this reasoning, the present study argues that IoT implementation is a key driver of smart warehouse development.

2.3 *Smart Warehouse and Supply Chain Performance*

Warehouses are no longer viewed merely as storage facilities but as strategic components of supply chain systems. Prior research indicates that smart warehouses contribute to improved supply chain performance by enhancing inventory accuracy, accelerating order fulfillment, and reducing logistics costs (Tubis & Rohman, 2023; Richards, 2017). These improvements directly affect key performance dimensions such as reliability, responsiveness, and flexibility.

Nevertheless, the literature also suggests that the performance benefits of smart warehouses are context-dependent. While manufacturing and retail sectors have demonstrated measurable gains, limited attention has been given to industries with extreme operational conditions, such as mining. The lack of empirical studies in this sector raises questions regarding the transferability of existing findings and highlights the need for industry-specific validation.

Given the operational complexity and high cost of disruptions in mining supply chains, smart warehouses may exert a stronger influence on performance compared to other sectors. Accordingly, this study proposes that smart warehouse implementation significantly enhances supply chain performance.

2.4 *The Mediating Role of Smart Warehouse*

Recent digital supply chain literature emphasizes that technology-driven performance improvements often occur through intermediate operational capabilities rather than through direct technological effects alone (Ben-Daya et al., 2019; Ivanov et al., 2022). In this regard, smart warehouses can be viewed as a mediating mechanism that converts IoT capabilities into tangible supply chain outcomes.

While several studies acknowledge the complementary relationship between IoT and warehouse digitalization, few empirically test the mediating role of smart warehouses. Most existing research examines these variables in isolation, thereby overlooking the process through which IoT adoption is operationalized.

This gap is particularly evident in the mining industry, where warehouse effectiveness is central to maintaining production stability.

By integrating IoT, smart warehouse, and supply chain performance into a single analytical framework, this study addresses this limitation and proposes a mediation relationship in which smart warehouses act as the operational bridge between IoT adoption and supply chain performance.

3. Method

This study employs a quantitative approach using a survey method, with a questionnaire as the primary data collection instrument. A quantitative approach was chosen because it provides measurable empirical evidence regarding the impact of Internet of Things (IoT) implementation in smart warehouses on the optimization of supply chain performance in mining companies. The population of this research consists of employees in mining companies who are directly involved in supply chain activities, particularly in warehouse, logistics, and inventory management divisions. The sampling technique used is purposive sampling, with the criterion that respondents must have at least two years of experience in logistics or warehouse management. The total sample size is set at 100 respondents, in accordance with the minimum recommendation for conducting Structural Equation Modeling–Partial Least Squares (SEM-PLS) analysis to ensure reliable and valid statistical models (Ghozali, 2021).

This sample size is justified based on methodological and practical considerations. First, according to the "10-times rule" commonly used in PLS-SEM, the minimum sample size should be at least ten times the largest number of structural paths directed at a particular construct. In this study, the maximum number of incoming paths to a construct is two, indicating a minimum requirement of 20 observations. Second, prior methodological guidelines suggest that a sample size between 50 and 150 is sufficient for reliable estimation in PLS-SEM models with medium effect sizes and reflective constructs (Hair et al., 2019). Therefore, a sample of 100 respondents is considered adequate to ensure statistical power while remaining feasible within the mining industry context, where access to respondents is often constrained.

The research instrument is a structured questionnaire designed using a five-point Likert scale, ranging from "strongly disagree" (1) to "strongly agree" (5). The variables measured include IoT implementation in smart warehouses (sensors, RFID, system integration, big data), warehouse performance (inventory accuracy, distribution speed, cost efficiency), and supply chain performance (responsiveness, reliability, flexibility, and operational cost). Prior to distribution, the questionnaire underwent content validity testing by logistics management experts, as well as a pilot test to examine the reliability of the instrument.

Data analysis was conducted using Structural Equation Modeling with the Partial Least Squares (SEM-PLS) approach, as this method is suitable for examining complex models with relatively small sample sizes and is capable of estimating causal relationships among latent variables. The analysis was carried out using Smart-PLS software, with several stages including convergent and discriminant validity testing, construct reliability assessment using Composite Reliability and Cronbach's Alpha, and hypothesis testing through the evaluation of path coefficients and the significance of t-statistics (Ghozali, 2021). The findings of this analysis are expected to provide empirical insights into the extent to which IoT implementation in smart warehouses contributes to the improvement of supply chain performance in mining companies, as well as to offer strategic recommendations for the development of technology-driven supply chain management practices.

Several potential sources of bias and methodological limitations should be acknowledged. First, the study relies on self-reported data, which may introduce common method bias and social desirability bias, as respondents may overestimate the effectiveness of IoT implementation or supply chain performance. To mitigate this risk, respondents were assured of anonymity and confidentiality, and the questionnaire was designed to minimize leading or evaluative wording.

Second, the cross-sectional nature of the data limits the ability to infer causality over time. While SEM-PLS allows for testing of theoretical causal relationships, longitudinal data would provide stronger evidence regarding the dynamic effects of IoT and smart warehouse implementation. Third, the use of purposive sampling may limit the generalizability of the findings beyond the mining industry or similar operational contexts. Additionally, the sample size, although methodologically adequate for PLS-SEM, remains relatively modest and may not fully capture heterogeneity across different mining firms.

Finally, this study focuses primarily on perceptual performance indicators rather than objective operational metrics such as actual cost savings or lead-time reductions. Future research is encouraged to combine survey data with archival or system-generated data to enhance measurement robustness.

Tabel 1. Operasional Variabel

Variable	Definition	Indicators	Measurement scale
Internet of Things (IoT) (X)	The implementation of IoT technology in smart warehouses, including the use of sensors, RFID, GPS, and real-time monitoring systems to improve inventory management and material distribution efficiency.	1. Use of sensors/RFID for inventory recording 2. Speed of real-time data access 3. Integration of warehouse systems with supply chains 4. Accuracy of inbound and outbound goods data 5. Efficiency in storage and distribution time	Ordinal
Smart Warehouse (M)	The effectiveness level of warehouse operations in supporting supply chains through optimized storage, recording, and distribution of materials.	1. Warehouse service speed (lead time) 2. Accuracy of inventory records 3. Utilization of storage space 4. Operational error rate 5. Flexibility in fulfilling demand	Ordinal
Supply Chain Performance (Y)	The ability of mining companies' supply chains to achieve efficiency, reliability, and responsiveness through IoT-enabled smart warehouses.	1. Logistics cost efficiency 2. Timeliness of material distribution 3. Internal and external user satisfaction 4. Smooth coordination among supply chain units 5. Adaptability to market demand changes	Ordinal

This study proposes a causal model assuming that the adoption of IoT in smart warehouses positively affects warehouse performance, which in turn enhances the supply chain performance of mining companies. In addition, IoT adoption may have a direct effect on supply chain performance, beyond its mediated effect through warehouse performance. This indicates a partial mediation mechanism, which provides a more comprehensive understanding of the role of digital technology in optimizing supply chain management in the mining sector.

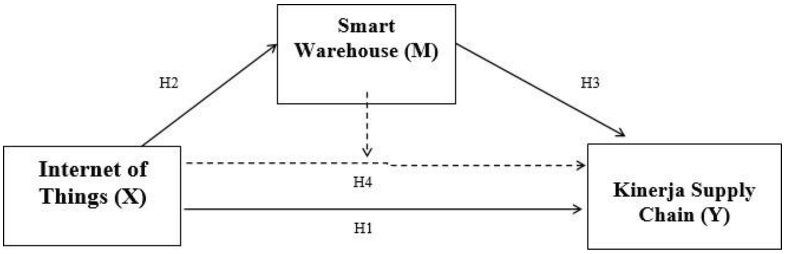

Figure 1. Conceptual Framework
Source: Modified Argyropoulou, M., Garcia, E., Nemati, S., & Spanaki, K. (2024)

Based on the conceptual framework and research model, the hypotheses proposed in this study are as follows:

1. **H1**: Internet of Things has a significant effect and increases the effectiveness of supply chain performance.
2. **H2**: Internet of Things has a strong influence on the development of smart warehouses.
3. **H3**: Smart warehouse has a significant influence on supply chain performance indicators.
4. **H4**: Smart warehouse significantly mediates the effect of Internet of Things on supply chain performance.

4. Result and Discussion

4.1 *Instrument Reliability Test*

After the questionnaire was confirmed to be valid, the next step was to conduct a reliability test to measure its consistency. Since the questionnaire is used repeatedly in the research, it is essential to ensure its reliability in measuring the studied variables. Cronbach's Alpha was used as the reliability indicator, with the following criteria: a value ≥ 0.9 indicates very high reliability; between 0.7 and 0.9 indicates high reliability; between 0.5 and 0.7 indicates moderate reliability; and values below 0.5 indicate low reliability (Ghozali, 2021). The results of the analysis show that all items used in this study have a high level of reliability, thus making them feasible for use, as shown below.

Tabel 2. *Reliability Test Results*

Variable	Cronbach's Alpha	Remark
Internet of Things	0.868	Reliable
Supply Chain Performance	0.911	Reliable
Smart Warehouse	0.938	Reliable

Source: Author's Research, Data Processed (2025)

The results of the reliability test indicate that all research variables have Cronbach's Alpha values above 0.70, which means they meet the reliability criteria. The Internet of Things (IoT) variable obtained a value of 0.868, signifying that the questionnaire items designed to measure IoT implementation in smart warehouses demonstrate a high level of internal consistency. The Supply Chain Performance variable recorded a value of 0.911, which also falls within the category of high reliability, confirming that the instrument is dependable for measuring the effectiveness of supply chain performance in mining companies. Meanwhile, the Smart Warehouse variable achieved the highest reliability score of 0.938, further emphasizing that the instrument exhibits very strong internal consistency.

4.2 *Coefficient of Determination (R^2)*

The extent to which the independent variables influence the dependent variables can be measured using the coefficient of determination (R-Square). The R-Square values obtained from the data analysis are as follows:

Tabel 3. *Coefficient of Determination*

Variable	**R Square**	**R Square Adjusted**
Supply Chain Performance	0.714	0.708
Smart Warehouse	0.756	0.753

Source: Author's Research, Data Processed (2025)

The results of the coefficient of determination test show that the Supply Chain Performance variable has an R-Square value of 0.714 and an Adjusted R-Square value of 0.708. This indicates that 71.4 percent of the variation in Supply Chain Performance can be explained by the independent variables used in the model, while the remaining 28.6 percent is explained by other factors outside the scope of this study. The Adjusted R-Square value, which is close to the R-Square, demonstrates that the research model is stable and does not experience significant reduction after adjusting for the number of predictors.

Meanwhile, the Smart Warehouse variable has an R-Square value of 0.756 and an Adjusted R-Square value of 0.753. This implies that 75.6 percent of the variation in Smart Warehouse can be explained by the independent variables in the model, whereas the remaining 24.4 percent is influenced by external factors not included in the study. The similarity between the Adjusted and R-Square values further confirms that the regression model used has strong predictive power and does not suffer from overfitting.

Overall, the R-Square values of both dependent variables are above 0.70, which can be categorized as high. This suggests that the research model is capable of explaining the majority of data variation effectively, making it reliable for drawing empirical conclusions regarding the implementation of the Internet of Things in smart warehouses and its impact on optimizing supply chain performance in the mining sector.

4.3 *SEM-PLS Analysis*

Evaluation of the Measurement Model (Outer Model)

According to Ghozali (2021), the outer model functions as the measurement model used to test the validity and reliability of a construct, while the inner model focuses on examining the causal relationships among latent variables. Convergent validity testing is conducted through measurement model parameters, including the loading factor values and the Average Variance Extracted (AVE), which serve as the primary indicators. Furthermore, discriminant validity is assessed using cross-loading values, whereas construct reliability is evaluated through Composite Reliability. By utilizing the SmartPLS software, the evaluation of the outer model can be performed, allowing the validity and reliability of each latent variable to be measured more accurately. The results of this data processing are then visualized in the form of the outer model, as presented in Figure 1.

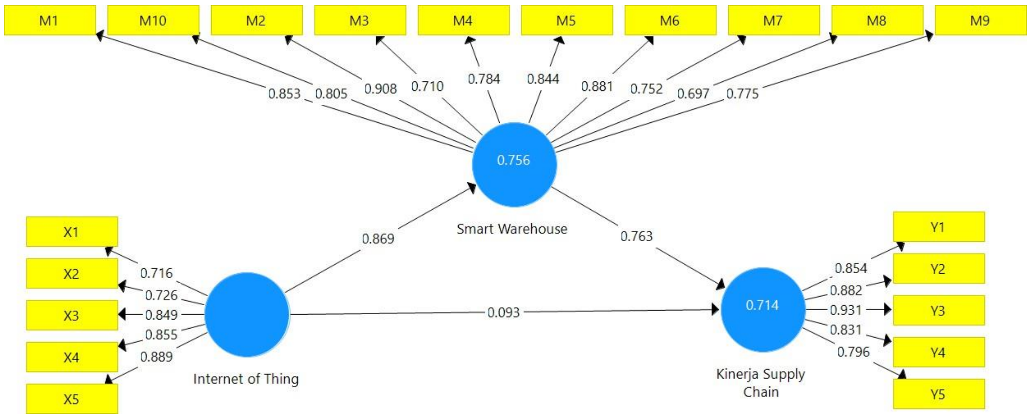

Figure 2. Outer Model

The initial analysis of the outer model indicates that all coefficient values between the variables and their indicators meet the established criteria for the outer model. This finding suggests that the model demonstrates good validity, reliability, and consistency.

Evaluation of the Outer Model

The outer model analysis is an evaluation stage used to assess the relationship between indicators and their corresponding latent variables. In this study, four main tests were conducted: convergent validity, composite reliability, Average Variance Extracted (AVE), and Cronbach's Alpha. A measurement model can be considered valid if the research instrument demonstrates consistency and accuracy in capturing the intended construct.

Tabel 4. *Construct Reliability and Validity*

Variable	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
Internet of Things	0.868	0.905	0.657
Supply Chain Performance	0.911	0.934	0.739
Smart Warehouse	0.938	0.948	0.646

Source: Author's Research, Data Processed (2025)

Based on the results of the reliability and validity tests, all variables in this study show Cronbach's Alpha values above 0.7, indicating that each construct demonstrates very good internal consistency. Specifically, the Cronbach's Alpha values for the Internet of Things, Supply Chain Performance, and Smart Warehouse are 0.868, 0.911, and 0.938, respectively, which confirms their reliability. Furthermore, the Composite Reliability (CR) values for all variables also exceed the threshold of 0.7, with Internet of Things at 0.905, Supply Chain Performance at 0.934, and Smart Warehouse at 0.948. This further reinforces the strong reliability of the instruments in measuring the latent constructs. In addition, the Average Variance Extracted (AVE) values are all above 0.5, namely 0.657 for Internet of Things, 0.739 for Supply Chain Performance, and 0.646 for Smart Warehouse. These values indicate that the indicators used are able to explain more than 50 percent of the variance in their respective constructs, thereby confirming convergent validity. Overall, the findings demonstrate that all variables in this study meet the criteria for reliability and validity, and thus are appropriate for further analysis in the structural model.

Evaluation of the Structural Model (Inner Model)

The analysis of the structural model (inner model) was conducted to examine the relationships among the latent variables proposed in the study. Hypothesis testing was carried out using the bootstrapping method in SmartPLS, which generates T-statistics and P-values. A T-statistics value greater than 1.96 with a significance level of P-value < 0.05 indicates that the hypothesis is accepted.

Tabel 5. *Hypothesis Testing Results*

	T Statistics (|O/STDEV|)	**P Values**
Internet of Things → Supply Chain Performance	9,140	0,000
Internet of Things → Smart Warehouse	37,527	0,000
Smart Warehouse → Supply Chain Performance	7,015	0,000
Internet of Things → Smart Warehouse → Supply Chain Performance	6,560	0,000

The hypothesis testing results presented in Table 5 reveal significant findings regarding the role of the Internet of Things (IoT) and smart warehouses in enhancing supply chain performance. First, the analysis shows that IoT has a significant impact on supply chain performance, with a T-value of 9.140 and P = 0.000. This finding confirms that the implementation of IoT contributes substantially to the effectiveness and efficiency of supply chains. By enabling real-time connectivity, data integration, and greater transparency in logistics processes, IoT reduces delays, minimizes errors, and accelerates the flow of goods and information. As a result, companies become more responsive to fluctuations in market demand and better equipped to manage supply chain uncertainties. This result is consistent with Ivanov et al. (2019), who emphasized that IoT serves as a key catalyst in enhancing supply chain flexibility and responsiveness in the digital era. Similarly, Mostafa et al. (2019) asserted that the adoption of IoT in warehouse management significantly improves efficiency and accuracy in supply chain operations. Moreover, Weng and Lin (2015) highlighted that IoT positively influences supply chain performance through competitive strategies and the integration of business processes.

Furthermore, the results indicate that IoT strongly influences the development of smart warehouses, as reflected by the high T-value of 37.527 and P = 0.000. This finding demonstrates that IoT technologies—such as radio frequency identification (RFID), smart sensors, global positioning systems (GPS), and real-time tracking systems—play a transformative role in shifting traditional warehousing systems toward smart warehouses. These technologies facilitate more accurate inventory control, real-time stock monitoring, and efficient operational management. Lee et al. (2022) emphasized that the adoption of IoT in warehouse management systems reduces lead times and improves inventory accuracy. Similarly, Firmansyah et al. (2024) confirmed that IoT-based smart warehouse designs enhance warehouse operational efficiency through real-time monitoring. In line with this, Wibowo and Santoso (2021) demonstrated that IoT-driven warehouse digitalization significantly contributes to improving overall supply chain efficiency. This supports the work of Gunasekaran et al. (2017), who argued that IoT is a fundamental driver in enabling warehouse digitalization and automation in modern logistics systems.

Then, the results confirm that smart warehouses have a significant effect on supply chain performance (T = 7.015; P = 0.000). Smart warehouses improve order fulfillment accuracy, shorten delivery lead times, and reduce operational costs through automation and integration. This finding reinforces the notion that warehouses are no longer mere storage facilities but strategic nodes in supply chains that directly affect distribution efficiency and customer satisfaction. Marques et al. (2020) similarly highlighted that warehouse digitalization through IoT integration enhances logistics accuracy, accelerates distribution processes, and ultimately strengthens overall supply chain performance. This is consistent with Tubis and Rohman (2023), who found that smart warehouse technologies have a direct impact on supply chain performance. Likewise, Sihaloho (2023) emphasized that the application of warehouse management systems improves inventory accuracy and distribution speed, thereby positively influencing supply chain performance. Furthermore, Wibowo and Santoso (2021) supported the view that warehouse digitalization and automation optimize supply chain integration across different industrial sectors.

Next, this study demonstrates that IoT significantly affects supply chain performance through the mediating role of smart warehouses, as shown by a T-value of 6.560 and P = 0.000. This indicates that the benefits of IoT are not only direct but also amplified through the optimization of smart warehouse systems. In other words, firms that successfully integrate IoT within their warehouse operations gain compounded improvements in supply chain performance. Al-Khatib (2023) also found that IoT enhances supply chain visibility, an effect reinforced by smart warehouses that leverage real-time data. Similarly, Argyropoulou et al. (2024) highlighted that IoT–smart warehouse integration significantly strengthens supply chain integration and performance. Consistently, Lee et al. (2022) confirmed that IoT-enabled smart warehouses improve inventory accuracy and accelerate order cycles, thereby indirectly enhancing overall supply chain performance.

The findings of this study confirm that IoT implementation has a significant positive effect on both Smart Warehouse utilization and Supply Chain Performance. However, beyond statistical confirmation, the underlying mechanism can be explained through how real-time data and automation reshape warehouse operations. In the mining industry, IoT sensors are used to track the availability and condition of spare parts and heavy equipment components. When inventory levels drop below a predefined threshold, the system automatically generates alerts and initiates the reordering process. This proactive data-driven mechanism minimizes stockouts and ensures that maintenance and production processes are not disrupted.

Furthermore, Smart Warehouse systems integrated with IoT enable automatic identification, real-time tracking, and efficient retrieval of materials. For instance, RFID tags attached to spare parts and IoT-based monitoring systems allow warehouse staff to locate and dispatch materials quickly, reducing search time and improving order fulfillment accuracy. These improvements directly enhance operational efficiency, which in turn strengthens overall Supply Chain Performance in mining operations.

From a managerial perspective, this implies that the adoption of IoT not only supports digital transformation but also provides tangible operational benefits by increasing visibility, coordination, and responsiveness across the supply chain. Theoretically, this reinforces the argument that digital connectivity acts as an enabler of supply chain agility and reliability. In this way, the integration of IoT and Smart Warehouse technologies offers a comprehensive explanation of how technological capability translates into measurable performance improvements within the mining sector.

Overall, this study provides empirical evidence that IoT and smart warehouses complement one another in strengthening supply chain performance. IoT acts as a digital enabler by enhancing visibility, transparency, and speed in logistics processes, while smart warehouses function as strategic mediators that translate technological input into tangible operational advantages through automation and system integration. The findings emphasize that the integration of IoT and Smart Warehouses is a key determinant in strengthening supply chain performance in mining companies. Successful implementation contributes to faster, more accurate, and efficient material distribution, ensuring operational sustainability. Thus, IoT adoption within Smart Warehouses not only supports internal efficiency but also fosters competitive advantage in the mining sector amid increasing global challenges. The main managerial implication of this study is the urgent need for digital transformation in mining supply chains, where IoT and Smart Warehouses must be prioritized as core strategies to enhance both operational efficiency and global competitiveness.

4.4 *Effect Size (f^2) Analysis and Discussion*

Beyond statistical significance, it is important to assess the effect size (f^2) to evaluate the substantive impact of each exogenous variable on the endogenous constructs. While t-values and p-values indicate whether relationships are statistically significant, effect size explains how strong and meaningful these relationships are in practice. Following Hair et al. (2019), effect size values of 0.02, 0.15, and 0.35 indicate small, medium, and large effects, respectively.

In this study, the R^2 values show that IoT and Smart Warehouse jointly explain 71.4% of the variance in Supply Chain Performance and 75.6% of the variance in Smart Warehouse, indicating strong predictive power. These high explanatory levels suggest that the structural relationships are not only statistically significant but also practically relevant.

The path from Internet of Things to Smart Warehouse demonstrates a very strong effect, as reflected by the high path coefficient and t-statistic. This indicates that IoT implementation plays a dominant role in shaping smart warehouse capabilities. Practically, this means that investments in IoT technologies—such as RFID, sensors, and real-time monitoring—have a substantial impact on warehouse digitalization, particularly in mining operations where manual handling and inventory complexity are prevalent.

The effect of Smart Warehouse on Supply Chain Performance can be categorized as moderate to strong, suggesting that improvements in warehouse automation, inventory accuracy, and distribution speed translate into meaningful performance gains across the supply chain. This finding confirms that smart warehouses function as critical operational nodes rather than passive storage facilities. In the mining context, where supply disruptions are costly, even moderate improvements in warehouse performance can generate significant operational benefits.

5. Conclusion

The findings of this study confirm that the implementation of the Internet of Things (IoT) and Smart Warehouse plays a highly significant role in improving supply chain performance, particularly in the mining sector, which is characterized by complex processes and high distribution demands. IoT has been proven to accelerate information flow, enhance data accuracy, and minimize errors in the distribution process. Meanwhile, smart warehouse serves as an essential hub for logistics integration, enabling warehouse automation, improving inventory efficiency, and accelerating delivery performance.

The results also reveal that Smart Warehouse functions as a mediator that strengthens the relationship between IoT and supply chain performance. This indicates that the integrated application of IoT and Smart Warehouse creates a more responsive, efficient, and competitive supply chain. Consequently, digital technology integration in the form of IoT and Smart Warehouse not only supports operational continuity but also acts as a strategic factor in addressing the challenges faced by the mining industry in the digital era.

From a managerial perspective, the findings offer several industry-specific implications for mining firms, where logistics disruptions are highly costly and operational continuity is critical. First, managers should view IoT adoption as a strategic investment rather than an IT expense. Although the initial costs of IoT implementation—such as RFID tags, sensors, warehouse management system upgrades, and network infrastructure—can be substantial, the benefits outweigh these costs when evaluated over the medium to long term. Improved inventory accuracy reduces the risk of stockouts and overstocking, both of which are particularly expensive in mining operations due to the high value of spare parts and the downtime costs associated with equipment failure.

Smart warehouse implementation can generate measurable cost savings by lowering manual labor requirements, minimizing inventory discrepancies, and reducing emergency procurement and expedited shipping costs. In mining contexts, even small improvements in warehouse efficiency can lead to significant financial benefits, as delays in material availability may halt production and cause substantial revenue losses. Thus, investments in warehouse automation and real-time tracking systems should be prioritized in high-impact storage areas, such as spare parts and critical consumables warehouses.

This study suggests that mining firms should adopt a phased implementation strategy to optimize the cost–benefit balance. Rather than pursuing full-scale digitalization at once, companies can begin with pilot projects in selected warehouses or material categories. This approach allows managers to evaluate performance improvements, calculate return on investment (ROI), and adjust system configurations before scaling up. Training programs for warehouse personnel should also be integrated into the investment plan, as human capability significantly influences the realization of technological benefits.

At the strategic level, the findings imply that digital warehouse transformation supports not only operational efficiency but also risk mitigation and supply chain resilience. By improving visibility and responsiveness, IoT-enabled Smart Warehouses help mining firms better manage uncertainties related to demand fluctuations, equipment maintenance needs, and geographical constraints. Despite its contributions, this study has several limitations. The analysis relies on perceptual data rather than objective financial metrics, which limits the ability to calculate precise cost savings and ROI values. Additionally, the cross-sectional design does not capture long-term cost–benefit dynamics. Future research is encouraged to incorporate longitudinal data, objective operational indicators (e.g., inventory turnover, downtime reduction, logistics cost ratios), and detailed cost–benefit or ROI analyses to further strengthen managerial decision-making in mining supply chains.

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References

Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of Things: A survey on enabling technologies, protocols, and applications. IEEE Communications Surveys & Tutorials, 17(4), 2347–2376.

Ashton, K. (2009). That 'Internet of Things' thing. RFID Journal, 22(7), 97–114.

Baruffaldi, G., Accorsi, R., & Manzini, R. (2019). Warehouse management system customization and design of the picking process. International Journal of Production Research, 57(5), 1440–1454. https://doi.org/10.1080/00207543.2018.1481303

Ben-Daya, M., Hassini, E., & Bahroun, Z. (2019). Internet of things and supply chain management: a literature review. International Journal of Production Research, 57(15-16), 4719–4742.

Chopra, S., & Meindl, P. (2019). Supply Chain Management: Strategy, Planning, and Operation (7th ed.). Pearson.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29(7), 1645–1660. https://doi.org/10.1016/j.future.2013.01.010.

Gunasekaran, A., Subramanian, N., & Papadopoulos, T. (2017). Information technology for competitive advantage within logistics and supply chains: A review. Transportation Research Part E: Logistics and Transportation Review, 99, 14–33.

Gunawan, A., & Rahayu, S. (2021). Performance measurement in mining supply chain management. Journal of Logistics, 14(2), 55–67.

Ivanov, D., Dolgui, A., & Sokolov, B. (2022). Handbook of Supply Chain Management: Digital, Resilient, and Sustainable. Springer.

Jarašūnienė, A., Čižiūnienė, K., & Čereška, A. (2023). Research on Impact of IoT on Warehouse Management. 23(4), 2213. https://doi.org/10.3390/s23042213.

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2020). Achieving sustainable performance in a data-driven agriculture supply chain: A review for the future. Computers and Electronics in Agriculture, 175, 105580.

Kusuma, D., Pratama, Y., & Lestari, R. (2020). Smart warehouse system based on IoT. International Journal of Supply Chain, 9(3), 88–96.

Lee, I., & Lee, K. (2015). The Internet of Things (IoT): Applications, investments, and challenges for enterprises. Business Horizons, 63(5), 657–670. https://doi.org/10.1016/j.bushor.2020.06.005.

Porter, M., & Heppelmann, J. (2019). How smart, connected products are transforming companies. Harvard Business Review, 97(5), 112–132.
Pratap, S., Jauhar, S. K., Gunasekaran, A., & Kamble, S. S. (2023). Optimizing the IoT and Big data Embedded Smart Supply Chains for Sustainable Performance. Computers & Industrial Engineering, 187, 109828. https://doi.org/10.1016/j.cie.2023.109828.
Purwanto, A., & Sari, R. (2023). Analisis efisiensi rantai pasok pada industri pertambangan di Indonesia. Jurnal Ekonomi dan Bisnis Indonesia, 38(1), 45–57.
Ramadhan, B., & Putri, N. (2021). IoT-based logistics management in Indonesian mining sector. Jurnal Teknologi Informasi, 15(2), 44–53.
Richards, G. (2017). Warehouse Management: A Complete Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse (3rd ed.). Kogan Page.
Seuring, S., & Müller, M. (2020). From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production, 250, 119–310. https://doi.org/10.1016/j.jclepro.2019.119310.
Sunaryo, A., & Santoso, B. (2021). Penerapan teknologi IoT dalam smart warehouse untuk meningkatkan efisiensi logistik. Jurnal Sistem Informasi dan Teknologi, 12(1), 23–34.
Suryanto, A., & Hakim, L. (2022). Challenges in mining supply chain management. Journal of Resource Management, 10(4), 215–228.
Tubis, A. A., & Rohman, J. (2023). Intelligent Warehouse in Industry 4.0—Systematic Literature Review. Sensors, 23(8), 4105. https://doi.org/10.3390/s23084105.
Wijaya, P., Setiawan, A., & Sari, M. (2023). Inventory management in mining companies: Issues and solutions. Journal of Business Logistics, 13(2), 99–110.
Wang, L., & Xu, X. (2022). Green and smart warehouse management: A framework for sustainable logistics. Computers & Industrial Engineering, 165, 107912. https://doi.org/10.1016/j.cie.2021.107912.
Zhou, K., Chong, A. Y. L., & Ngai, E. W. T. (2021). Supply chain management in the era of the Internet of Things. International Journal of Production Economics, 231, 107861. https://doi.org/10.1016/j.ijpe.2020.107861.
Büyüközkan, G., & Göçer, F. (2018). Digital supply chain: Literature review and a proposed framework for future research. Computers in Industry, 97, 157–177. https://doi.org/10.1016/j.compind.2018.02.010.
Gunasekaran, A., Subramanian, N., & Papadopoulos, T. (2017). Information technology for competitive advantage within logistics and supply chains: A review. International Journal of Information Management, 37(1), 1–15. https://doi.org/10.1016/j.ijinfomgt.2016.09.003.
Ivanov, D., Dolgui, A., Sokolov, B., Werner, F., & Ivanova, M. (2019). A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory Industry 4.0. International Journal of Production Research, 57(2), 590–606. https://doi.org/10.1080/00207543.2018.1504248.
Marques, A. D., Agostinho, C., Zacharewicz, G., & Jardim-Gonçalves, R. (2020). Decentralized decision support for intelligent manufacturing in Industry 4.0. Computers & Industrial Engineering, 139, 106193. https://doi.org/10.1016/j.cie.2019.01.034.