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The effectiveness of IoT use on supply chain management under extreme conditions in the copper cleaner project in the PT XYZ area

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ABSTRACT

This study examines the effectiveness of IoT technology in enhancing Supply Chain Management (SCM) under extreme conditions, focusing on the copper cleaner project at PT XYZ, located in a remote mountainous area at 2,300 meters above sea level. The research addresses challenges such as difficult terrain, high transportation costs, and unpredictable weather, all of which disrupt logistics processes and project timelines. The primary objective is to analyze how IoT implementation improves supply chain efficiency, reduces shipment delays, and optimizes logistics costs. Utilizing a mixed-method approach, the study combines quantitative data (e.g., delivery times, transportation costs) with qualitative insights from stakeholder interviews and field observations. Findings reveal that IoT adoption reduced delivery delays by 13%, increased on-time delivery reliability to 85%, and lowered additional logistics costs by up to 20%. Key supply chain metrics such as error frequency, transportation costs, and inventory holding costs were significantly optimized, thereby enhancing overall project performance. The study underscores the strategic role of IoT in mitigating supply chain risks and improving operational efficiency in extreme environments. The implications suggest that technology-driven SCM can serve as a transformative solution for similar projects, fostering sustainability and customer satisfaction.

KEYWORDS *Supply Chain Integration Method, Supply Chain Integration, Supply Chain Management*

INTRODUCTION

The implementation of construction projects often faces various challenges, such as delays in completion and stalled execution (Durdyev & Hosseini, 2020; Govindasamy & Bekker, 2024; Iqbal et al., 2015; Mahmoud al-Mukahal, 2020). These issues require effective control measures to minimize deviations, ensuring that the project can be completed on time and with the desired quality according to the plan. The success of a project is determined by the integration of planning, execution, and supervision stages, as well as the application of efficient management techniques to improve productivity and work quality (Kumari & Mallesham, 2020; Mahmood et al., 2023; Peral et al., 2019; Shewale et al., 2022; Tabassum et al., 2020). Planning plays a critical role in ensuring the efficient use of resources, both human and material, throughout the project lifecycle.

In this context, Supply Chain Management (SCM) is a crucial element, particularly in construction planning and resource management. However, managing SCM in extreme areas, such as regions located above 2,300 meters above sea level, presents unique challenges (Boonsthonsatit S., 2015; Choi, 2020; Gurtu & Johny, 2021; Itang et al., 2022; Wen et al., 2019). Extreme areas, such as PT XYZ's operational sites, possess abundant natural resources but limited accessibility due to difficult terrain, high transportation costs, and the risk of natural disasters. Additionally, *climate change* affecting weather patterns poses further obstacles within the supply chain. These challenges necessitate innovative and adaptive SCM strategies to ensure that procurement, production, and distribution processes can operate effectively.

Research by Christopher (2016) states that technology-based SCM, such as the use of the *Internet of Things (IoT)* and *blockchain*, can increase transparency and efficiency in supply chain processes, especially in remote locations. Extreme locations, such as mountainous or remote areas, require a unique approach to logistics. According to Ghiani et al. (2013), the main challenges in logistics within extreme locations include: (a) minimal or inadequate infrastructure, (b) unpredictable weather, and (c) risks to the safety of goods transportation.

The main purpose of this study is to analyze the impact of IoT technology implementation on increasing efficiency and effectiveness in supply chain management within the research area. Thus, the results are expected to provide valuable insights for companies, academics, and supply chain management practitioners to optimize their supply chain operations. The benefits include increased operational efficiency, risk mitigation, and enhanced trust throughout the supply chain.

RESEARCH METHOD

This study used a quantitative approach with a case study method to explore in depth how PT XYZ managed the supply chain in various environmental conditions. This method was chosen to understand the dynamics and strategies applied in facing existing challenges. The selection of case studies as the primary research method allowed researchers to explore IoT implementations on a real scale.

To explore the application of Supply Chain Management (SCM) in the extreme areas that were the focus of this research, the necessary data included variables that affected the supply chain process at PT XYZ. This research required two types of data, namely: quantitative data as the main data and qualitative data as supporting data. The quantitative data referred to in this study were data that measured aspects to be calculated and analyzed statistically. The types of quantitative data collected included delivery time, shipping costs, and the volume of goods delivered. Meanwhile, the qualitative data referred to in this study were data that provided an in-depth overview of operational conditions in the field, as well as the views and experiences of parties involved in the supply chain. The type of qualitative data collected included interviews with stakeholders directly involved in supply chain management to understand challenges and conditions on the ground.

The data sources in this study used internal documentation data of PT XYZ and partners related to supply chain management, obtained from operational reports and internal records owned by PT XYZ. This documentation included historical data regarding the delivery of goods, logistics costs, delivery times, as well as information related to damage or disruption that occurred due to natural disasters or extreme weather conditions. There were also interview data conducted with various parties who had direct experience in the supply chain, such as project managers and logistics management staff at PT XYZ who could provide views on supply chain planning and management, and also data obtained from transportation partners who worked with PT XYZ and had experience in dealing with geographical and weather constraints. Direct observation was carried out to observe physical conditions in the field, such as the road terrain that vehicles passed, as well as the process of delivering materials. Researchers noted the obstacles that arose in hard-to-reach areas and how SCM management was carried out to overcome these challenges.

Information from interviews, observations, and internal documentation was combined to build a comprehensive picture of the application of IoT technology in improving efficiency and effectiveness in supply chain management in the research area. The data collected was analyzed using quantitative approaches and statistical analysis. This analysis helped identify emerging trends, challenges, and benefits to ensure the validity and reliability of the research.

Through a combination of case studies, in-depth interviews, and field observations, this research method was expected to provide in-depth and comprehensive insights to analyze the impact of IoT technology application in improving efficiency and effectiveness in supply chain management in the research area.

RESULT AND DISCUSSION

PT XYZ's operational area has rich natural resources but limited accessibility, the copper cleaner project itself is located at an altitude of 2300 meters above sea level and is located at mill 74, which means that the project location is located on a mountain and is 74 mill or 119 km from the port. With difficult terrain conditions, high transportation costs, frequent weather changes and the risk of natural disasters, innovative and adaptive Supply Chain Management strategies are needed so that the procurement, production, and distribution processes can run well. Effective Supply Chain Management includes three main aspects, namely cost efficiency, speed of distribution, and customer satisfaction.

Based on the results of the field study, the following data are known:

Table 1. Project Schedule Data

Phase	Planned Duration (days)	Actual Duration (days)	Delay (%)
Foundation	30	35	16,7
Structure	60	75	25
Finishing	45	50	11,1

Broadly speaking, the work on this project is divided into three stages, the first stage is the foundation with a target of 30 working days, then the structure stage with a target of 60 working days and the last stage of finishing with a target of 45 working days. It can be seen in Table 1. In the second phase of the project implementation, there was a discrepancy between the estimated day and the actual conditions, so the company piloted to apply IoT (Internet of Things) to the logistics process as an innovation and a step to support the success of Supply Chain Management.

Table 2. Logistics Data and IoT Usage

Transport ID	Transport Time (hours)	Delay Frequency (%)	Logistics Cost ($)	IoT Used
T1	8	30	3000	Yes
T2	10	40	3500	No
T3	12	25	4000	Yes
T4	7	20	2500	No
T5	9	35	3200	No
T6	11	15	3800	Yes
T7	10	40	3400	No
T8	12	30	3900	Yes
T9	6	10	2800	Yes
T10	8	25	3100	No

It can be seen in Table 2. The company made 10 deliveries in the finishing phase, of which 5 out of 10 deliveries used IoT technology as a measure to minimize the delay in the planned estimated working days. And it was found that the use of IoT at the finishing stage can reduce the actual value of the planned workday by 13%.

Table 3. Project Cost Data

Phase	Planned Cost ($)	Actual Cost ($)	Extra Cost Due to Delay ($)
Foundation	100.000	115.000	15.000
Structure	250.000	290.000	40.000
Finishing	150.000	165.000	15.000

The cost of working on this project has swelled due to the discrepancy between the estimated day and the actual condition. It can be seen in Table 4.3 that in the first phase there was a cost overrun of $15,000 but in the second phase of the project implementation the cost overrun was actually $40,000 due to a delay of 25% of the planned time. Because of this, at the finishing stage, 5 out of 10 deliveries are carried out using IoT technology as a step to minimize the delay in the estimated working days that have been planned. And this is also a step to minimize the cost overrun that has occurred in the previous stage, at the finishing stage the cost overrun can be reduced to $15,000 from the previous $40,000.

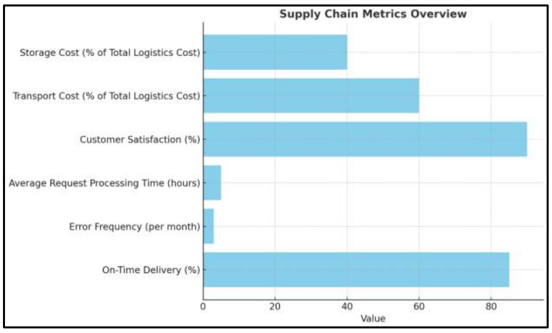


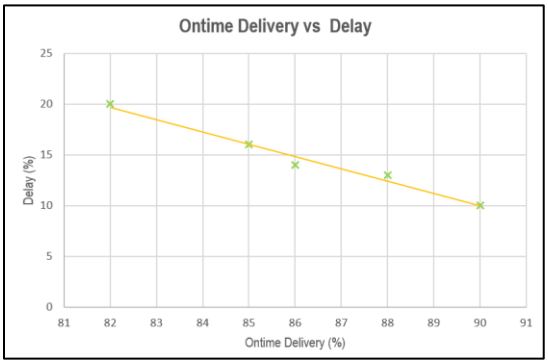
Figure 1. Data Supply Chain Metrics

In Figure 1. It can be seen that the condition of the supply chain on-time delivery reliability of 85% shows a fairly good level of delivery reliability, but there is still an opportunity for improvement where if on-time delivery has a high value and has a low error value, the project schedule is more maintained. The Error Frequency value of 3 per month indicates that the logistics system still faces several operational obstacles regarding the discrepancy between the estimated day and the actual condition.

In the supply chain responsiveness assessment, an average request processing time of 5 hours was obtained, which indicates that the efficiency in responding to logistics needs is not good enough so optimization is needed. With a fairly good supply chain reliability value, a customer satisfaction response of 90% was obtained, which shows that customers are satisfied with the performance of the system.

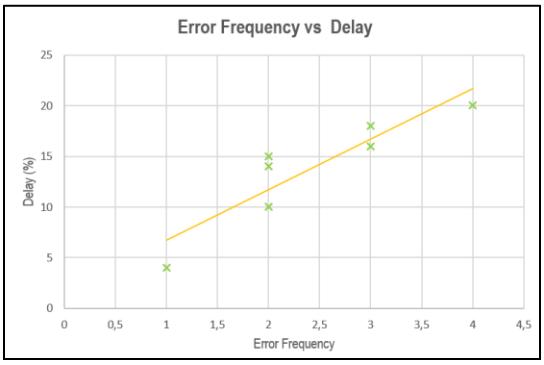
It is known that Supply chain cost is a total logistic cost consisting of Transport Cost and Storage Cost. In these field conditions, the value of Transport Cost reaches 60% which is the main component of the total logistics cost, indicating the need to optimize routes and vehicles so that it can reduce additional costs arising from delays. As for the allocation of Storage Cost, a value of 40% was obtained which made a significant contribution so that the data obtained showed the importance of efficient inventory management.

From all supply chain metrics parameters, it can be seen that these elements affect delays and potentially incur additional costs. Schedule efficiency is greatly affected by delivery timeliness and operational errors, project costs can be reduced if transportation costs and storage costs can be carried out efficiently.



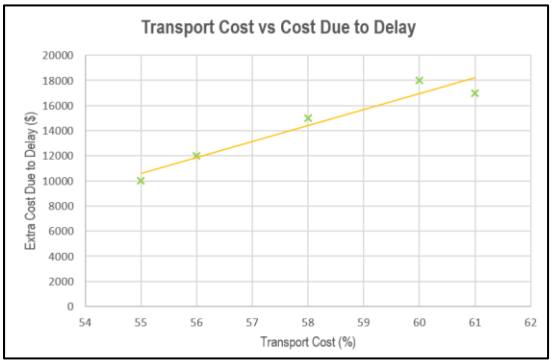
Graphic 1.Graphic On Time Delivery vs Delay

On-time delivery shows the timeliness of delivery so that it is closely related to the delay that occurs in the project in Graph 1. Ontime delivery vs Delay shows that the higher the on-time delivery rate, the lower the project delay rate. This trend is supported by a regression line that shows that the relationship between the two variables is negative. By knowing the effectiveness of the material schedule to the project site, the availability of materials can be fulfilled on time.



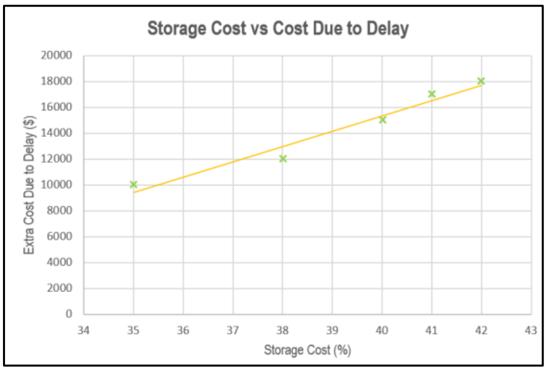
Graph 2.Error Frequency vs Delay Graph

Error Frequency shows the frequency of errors in the delivery process that are closely related to the Delay that occurs in the project in Figure 2. Error Frequency vs Delay shows that the smaller the frequency of error rates in delivery, the lower the project delay rate. This trend line shows that the relationship between the two variables is positive, which means that reducing the frequency of errors can reduce the delay time.



Graphic 3.Graphic Transport Cost vs Cost Due to Delay

Transport Cost shows the costs needed in the delivery process so that it is closely related to Cost Due to Delay which means that there are additional costs incurred if delays occur in the project in Graph 3. Transport Cost vs Delay shows that inefficient transportation costs can increase additional costs, the transportation cost required is an average of 60% of the total logistics cost with a large contribution to the additional cost of $15,000-$18,000. This trend line shows that the relationship between the two variables is positive, which means that the large shipping costs are directly proportional to the additional costs incurred if delays occur in the project.



Graphic 4.Grafik Storage Cost vs Cost Due to Delay

Storage Cost shows the costs needed in the process of storing goods so that careful planning needs to be carried out and related to the timeliness of delivery, this is also closely related to Cost Due to Delay which means that there are additional costs incurred if there is an extension of the storage time of goods in the project in Graph 4. Storage Cost vs Delay shows that inefficient storage costs due to lack of planning or irregular stock accumulation can increase additional costs, the storage cost required averages 40% of the total logistics cost with a large contribution to the additional costs of $5,000-$18,000.

From the results of the study, a strong correlation was obtained that the variables Error Frequency and On-Time Delivery greatly affected the project schedule and cost. Higher error frequencies adversely affect project efficiency.

Meanwhile, Transport Cost has a greater impact than Storage Cost. Schedule and Cost Linkage can explain schedule misalignments (delays) and high additional costs indicate the need for optimization in logistics components such as transportation and storage. Application of Technology The implementation of IoT technology-based systems for inventory monitoring and logistics, can be a solution to increase efficiency. The Strategic Impact that can be seen is that logistics optimization not only reduces additional costs due to delays but also improves customer satisfaction and project sustainability.

The implementation of an optimal SCM strategy not only impacts project efficiency, but also increases customer satisfaction (90% as shown in Figure 1. By leveraging IoT technology, companies can reduce project delays by 16% and additional costs by up to 20%.

Overall, this discussion shows that the elements in SCM are interrelated. Inefficiencies in any one element can create a domino effect that affects the entire project. Therefore, a holistic approach involving technology and risk management is needed to ensure the success of the project, especially in extreme locations.

CONCLUSION

The study demonstrated that implementing Supply Chain Management (SCM) supported by Internet of Things (IoT) technology in construction projects located in extreme environments significantly improved logistics efficiency, reduced delivery delays by up to 13%, and increased delivery reliability to 85%. The optimization of transportation and storage costs contributed to a substantial reduction in additional expenses, which typically account for 60% of total logistics costs, with savings of up to $15,000 achieved at the finishing stage despite incurring $40,000 in extra costs during the structure phase. Furthermore, technology-based SCM enhanced operational efficiency by up to 90% and improved customer satisfaction. The study highlighted the importance of scheduling shipments based on weather analysis and utilizing logistics insurance to mitigate risks in challenging locations. For future research, it is suggested to further investigate the use of advanced, data-driven simulation models to anticipate and manage complex risks—such as rapidly changing weather patterns—to support even more resilient and adaptive supply chain strategies in extreme environments.

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