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Strand Inventory Analysis of Post Tension in PT XYZ Using Discrete-Event Simulation Method

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Abstract

The development of connectivity infrastructure, particularly toll roads, is planned to continue expanding and reach 3,500 km by 2030. This signifies a positive outlook for the construction industry. This research conducted to analyse the management of post tension raw materials and determine the optimal policies using the discrete-event simulation method. Simulation scenarios were developed using the Arena application, taking into consideration the demand patterns for post tension work. The validation test results confirmed the capability of the base case model in accurately representing real-world conditions. Scenario development was carried out to influence the strand inventory pattern by incorporating reorder points and adjusting order sizes. Based on the scenario analysis, the most effective approach was found to be setting a reorder point of 3 tons and an order size of 5 tons. The implementation of this analysis successfully reduced the strand inventory by 58.78%. This research enables companies to optimize their inventory, reduce costs, and enhance operational efficiency. The findings contribute to the development of strategies that support sustainable growth in connectivity infrastructure in Indonesia.

Keywords: strand; post tension; inventory; discrete-event simulation; infastructure

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1. Introduction

Road construction or infrastructure development activities are ongoing and evolving processes. The availability of infrastructure that connects different regions can significantly boost economic activities in each respective area. However, there is still an infrastructure gap in Indonesia due to a lack of investment in the infrastructure sector (Kementerian Bidang Perekonomian, 2022). To drive national economic growth, the government has issued Minister of Economy Regulation No. 9 of 2022, which aims to prioritize infrastructure projects through the National Strategic Projects program. This program includes the development of 53 toll roads located in different regions throughout Indonesia. (Limanseto, 2022).

This is also in line with the program of the Ministry of Public Works and People's Housing of the Republic of Indonesia, which is responsible for road infrastructure in Indonesia. (Perpres. RI. No. 27, 2020). The Ministry of Public Works and People's Housing (PUPR) through its Strategic Plan for 2020-2024 aims to develop connectivity infrastructure, primarily to improve the availability of road networks that support regional development. This will be achieved by constructing roads on major inter-island routes, roads that support priority industrial and tourism areas, access roads to priority transportation hubs, outer ring roads/inter-island roads, and access roads supporting remote, disadvantaged, and border areas. (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2020). This is a positive indication for the infrastructure construction industry, both for toll roads and non-toll roads. The development of toll roads is projected to expand by 1,500 kilometers with a total budget of 330 trillion rupiahs, and it is expected to continue growing with the addition of 5,070 kilometers of toll roads and new roads in 2023.(Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2020).

Infrastructure development typically includes bridges. A bridge is a structure designed to carry a road or pathway over an obstacle that is positioned at a lower elevation. This obstacle is usually another road (such as a body of water or a

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regular traffic route) (Struyk & Veen, 1994). Bridge construction typically involves various types of concrete, including fresh concrete (readymix) and prestressed concrete (precast concrete). Precast concrete is distinguished based on two manufacturing methods: pre-tension and post-tension. (Dadang, 2017).

Table 1. COGM for Post Tension

Components	% of Cost
Post tension process 1	9%
Post tension process 2	4%
Post tension process 6	6%
Post tension process 7	0%
Block 12W13	11%
Wedges W13	4%
Strand dia 12,7 mm	58%
Cement Type 1	2%
Consol Expander	0%
Consol 71EP	5%

Source: Author's Analysis

The use of post-tensioning allows for the creation of a more slender and lightweight system, resulting in benefits in terms of performance and time. As a result, the total construction costs can be substantially reduced (Post-Tension in Building, 2005).

One of the manufacturing-construction companies in Indonesia is PT XYZ, which provides post-tensioning services. According to PT XYZ's data (2022), nearly 80% of the cost of goods manufactured (COGM) components in post-tensioning activities are dominated by raw materials, as shown in Table 1. Among the various raw material components of post-tensioning, Strand is the component with the highest production cost percentage, accounting for 58%.

In general, raw material costs can account for approximately 50% to 60% of the total construction project costs (Lu et al., 2018). Therefore, the existence of Strand inventory as one of the raw material components will have a significant impact on the company, particularly in its fund allocation management. Hence, effective inventory management is crucial to maximize profits and minimize potential risks that may arise in the future.

Inventory management of raw materials in the construction industry is a complex task due to various influencing factors, such as changing project locations and heavy reliance on field conditions. Thus, the discrete event simulation method can be utilized for inventory analysis in construction companies, as this method can help expand classical models with more realistic assumptions. (Davoli & Melloni, 2012).

This research is a continuation of the study that has been conducted by Milewski & Wiśniewski (2022) regarding the simplification of complex relationships between determining the quantity of shipments that will affect shipping costs, inventory costs, and warehousing costs, along with the potential for lost sales if adjustments are made, using simulation methods. This method is used to obtain the optimal batch size for shipments, as in the previous research (Milewski, 2019) it has been proven that the size of shipments and the level of safety stock significantly affect the performance of the company. Simulations have also demonstrated (Lu, Wang, Xie, & Wang, 2018) that not only the level of safety stock, but also the frequency and size of shipments affect the level of logistics customer service measured by stock availability. Both studies conducted by Milewski (2019) and Milewski & Wiśniewski (2022) using a sample from the fast-moving consumer goods (FMCG) industry, which exhibits a demand pattern that follows a normal distribution. In other industries, particularly the construction industry, there is a lack of research on similar topics, despite the fact that this industry experiences uncertain demand for raw materials. Further research is needed to achieve optimal company performance in this context.

This study will employ simulation methods to analyze the inventory of Strand at PT XYZ using the ARENA software. The findings of this research are expected to assist PT XYZ and other construction companies in effectively managing their inventory.

Several relevant literature sources related to the above issues are as follows. In the previous discussion, we touched upon concrete as a material used in bridge construction. Concrete is known in the construction industry as a mixture of materials including gravel, sand, cement, and water, which is resistant to compression but not to tension (Diphohusodo, 1993). To reinforce the structure, a combination of materials is used to withstand tensile forces, and one of these materials is steel. Steel is highly resistant to tension. By combining concrete and steel (with concrete bearing compression and steel bearing tension), concrete becomes a material that can withstand both compression and tension, known as reinforced concrete. If the reinforced concrete is subjected to internal stress, it becomes prestressed concrete (Tumpu, Rangan, Kristen, & Toraja, 2022).

Prestressed concrete is classified into two methods of construction, namely pre-tensioning and post-tensioning. In most countries, the use of prestressed concrete in building structures is commonly done in the form of pre-tensioned elements that have been stressed beforehand. On the other hand, post-tensioning is more commonly used in bridge construction due to its suitability for field conditions, providing space for grouting, and requiring heavy-duty tensioning equipment (Post-Tensioning in Buildings, 2005).

Despite its well-known benefits and simple concept, the level of post-tensioning application is not consistent across various fields and structural applications. For various reasons, the potential offered by prestressing has not been fully utilized, especially in the field of building structures. In many cases where post-tensioning would provide a far superior solution, conventional non-prestressed solutions are still chosen (Post-Tensioning in Buildings, 2005).

To maximize the benefits of using the post-tensioning method, it is also necessary to consider uncertainties in the material's demand and supply processes. Especially uncertainties that arise from scheduling allocation, costs, demand, schedule-cost, and schedule-demand (Lu et al., 2018). Managing inventory involves the processes of demand and supply for materials. Ensuring the continuity of production activities requires assessing suppliers (Winter & Lasch, 2016) It is an effort by the company to maintain the sustainability and performance of its supply chain. (Beske-Janssen, Johnson, & Schaltegger, 2015) Several benefits need to be considered in inventory management to avoid disruptions in the production process (Heizer & Render, 2020):

a) Inventory provides various product options to meet customer demand and protects the company from fluctuations in customer demand.

b) Inventory allows different parts of the production process to be carried out separately.

c) Inventory enables the company to take advantage of quantity discounts, as larger purchases can lower the unit cost.

d) Inventory helps the company hedge against inflation and price increases.

Inventory management and control should be a top priority for management. Planning involves determining the quantity of raw materials to be ordered, as well as when and how often, in order to minimize costs (Raju, 2022). This poses a challenge in the construction industry as the supply chain in this sector is vast and complex (Lu et al., 2018).

Inventory costs in the Construction Supply Chain (CSC) management mode are significantly lower compared to the Economic Order Quantity (EOQ) model (Yang et al., 2018). Inventory costs include opportunity costs, storage space costs, and ordering costs. The selection of suppliers is highly dependent on these inventory costs (Mohammadnazari & Ghannadpour, 2021).

Meanwhile, the supply chain structure for traditional construction projects typically consists of multiple raw material suppliers who directly deliver to the construction site, and rarely involves the use of consolidation centers for temporary storage (Hsu, Angeloudis, & Aurisicchio, 2018).

Previous studies have shown that the source of these issues lies in the complex nature and characteristics of the construction environment, thus requiring optimization models to reduce costs while maintaining efficiency throughout the supply chain.

Meanwhile, Milewski & Wiśniewski (2022) A study conducted in Poland, which examined the supply chain in the construction industry using simulation methods, demonstrated that the size of shipments and the amount of safety stock significantly impact company performance. However, the impact varies depending on different factors, such as the value of goods, demand stability, and logistics process costs. Inventory costs are estimated to reach 26% of the value of goods (Heizer & Render, 2020). Therefore, effective inventory strategies are key to achieving profitability (Xiong, Li, Yang, & Shen, 2022).

2. Research Method and Materials

This study utilizes quantitative analysis. According to Render, Barry & Stair, Ralph (2018), Quantitative analysis is a method or tool that management can use to make decisions and solve problems. In many real-world systems, the complexity is too high to be directly evaluated. Therefore, problem-solving is often approached by simulating or imitating the system, which is known as simulation (Milewski & Wiśniewski, 2022). In simulation, computer programs are used to develop and evaluate models numerically, and data collection is conducted to estimate the characteristics of the real system (Law, 2015). Simulation modeling is a common paradigm for analyzing complex systems (Altiok & Benjamin, 2020).

This research utilizes a discrete event simulation approach. The model in this study is modified based on the simulation model developed by Milewski & Wiśniewski (2022). The objective of this research is to determine the reorder point and safety stock while considering various aspects such as cost incurred and non-productive time, in order to reduce potential risks and wastage in the future.

In this study, historical data from a manufacturing-construction company in Indonesia from January 2022 to March 2022 were used. This period was chosen as it was the busiest period in 2022, preparing for road infrastructure before the Eid al-Fitr holiday. The historical data includes:

- Monthly inventory data for raw materials
- Data on raw material usage
- Production demand data
- Data from supplier partners to meet raw material requirements, such as lead time data (3 days) and minimum order size (30 tons)
- The collected data was then used as assumptions for the simulation program. The assumptions used in developing the simulation model using Arena are as follows:
- Replication time is 90 days, equivalent to 1 quarter, adjusting to the historical data used.
- Each day consists of 24 hours.
- Warm-up time is 30 minutes.
- Replication is performed 100 times.
- There are no disruptions in the entire post-tension production process.
- There are no disruptions in the procurement request generation process.
- There are no disruptions in the goods delivery process.
- There are no errors or anomalies in recording demand, offers, and other data.
- There are no exceptional events that result in a significant surge in strand usage.

This research was conducted following the steps outlined in Figure 1.

The seven stages of the research:

a) Identification of the research focus, which is the inventory management modeling of Strand, followed by a literature review related to the problem.

b) Based on interviews and collected data, the analysis of input probability distribution is conducted using input analyzer in the Arena software.

c) The next step is to develop a simulation model for the current condition (base case scenario) based on the inventory management activities of Strand at PT XYZ. The model is then checked for errors (verification process).

d) Once the base case scenario model is error-free, the validation process is conducted to determine if the developed model is valid and represents the real system (Law, 2015). In this study, validation is done by determining the confidence interval of the compared parameter (X) using the following formula:

$$\bar{X}(n) \pm t_{n-1,1-\frac{\alpha}{2}}\sqrt{\frac{S_x^2(n)}{n}} \qquad (1)$$

With:

$\bar{X}(n)$ = Mean of the model dataset

$S_x^2(n)$ = Variance of the model dataset

n = Number of *data set*
α = Significance level
t = Critical value of the t-distribution

If the actual average usage of Strand falls within this confidence interval, then the simulation model is considered valid. If the model is still invalid, modifications to the model are necessary. The parameter used for model validation in this case is the Strand usage per quarter.

e) Based on the existing base case model, several alternative improvement scenarios are created.

f) Next, scenario analysis is conducted to determine the best inventory management scenario. Paired t-test is used for this analysis, using the following formula:

$$\bar{Z}(n) \pm t_{n-1,1-\frac{\alpha}{2}}\sqrt{\widehat{Var}[\bar{Z}(n)]} \quad (2)$$

With,
$\bar{Z}(n)$ = Mean difference of the model datasets 1 and 2
$\widehat{Var}[\bar{Z}(n)]$ = Variance of the mean difference of the datasets 1 and 2
n = Number of datasets in the system
α = Significance level
t = Critical value of the t-distribution

If the confidence interval between the base case model and alternative scenarios does not include zero, then those scenarios are considered significantly different (Law, 2015).

g) The selected alternative scenario is the one that is significantly different from the base case model and has the lowest average inventory value. This scenario is recommended as the inventory policy that can be used by PT XYZ.

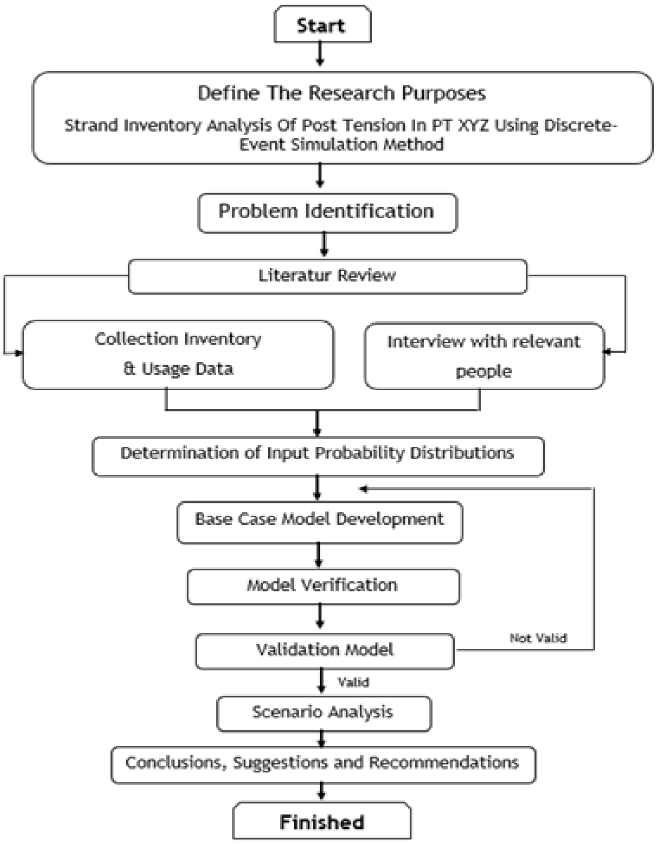

Figure 1. Research Framework

3. Results and Discussion

This research was conducted in a manufacturing-construction company in Indonesia. One of the products provided by the company is post-tension work, which requires strand as one of its component materials. As stated in Table 1, the position of strand plays a significant role in post-tension work, as any issues in managing the inventory of strand can disrupt the business process, particularly in terms of cash flow. Therefore, proper management of strand inventory is necessary to avoid potential problems.

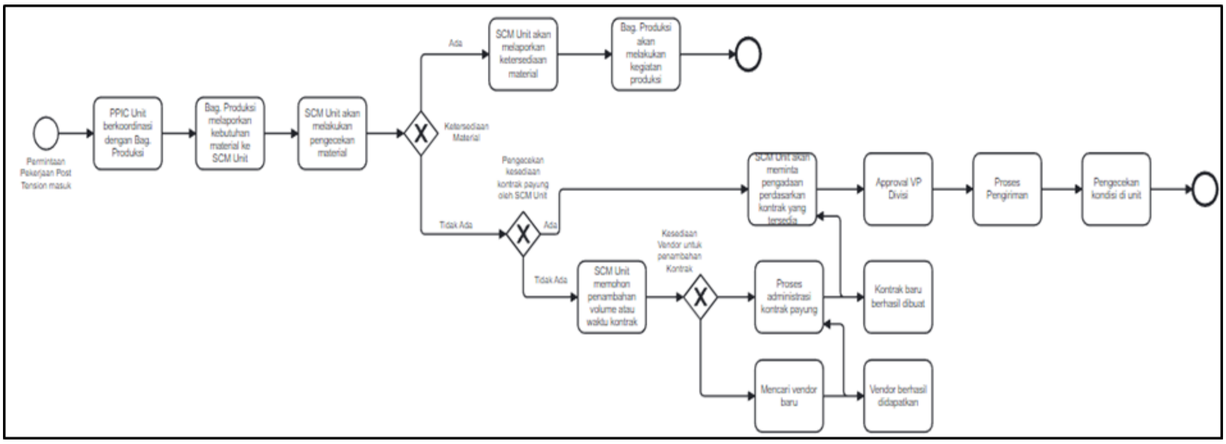

Figure 2. *Strand* Inventory Management in PT XYZ

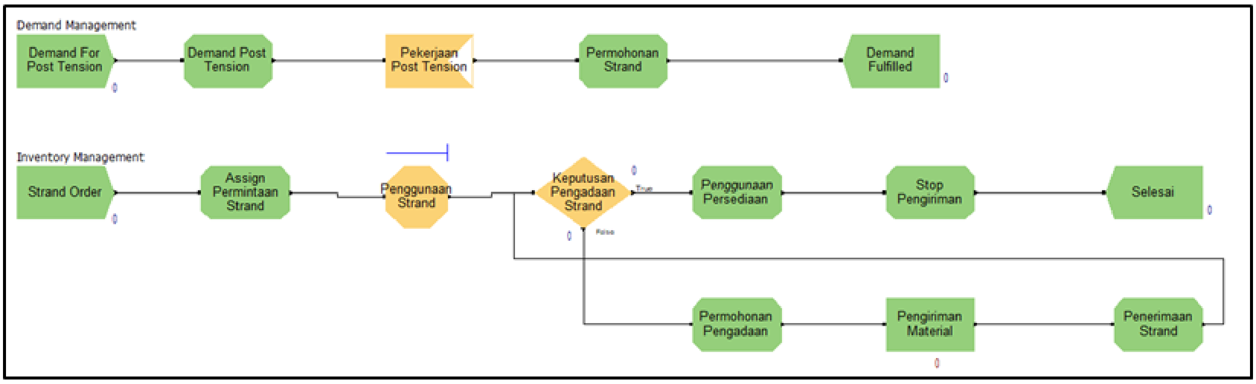

Figure 3. Simulation Model

The process of managing the strand at PT XYZ is carried out through several stages with designated persons in charge (PIC), as shown in Figure 2. The procurement process begins with submitting a request for strand procurement based on the strand needs to the Supply Chain Management (SCM) department. After a thorough check by SCM, the request is forwarded to the central division for verification. The verification process continues until the Vice President releases the request, indicating its approval. Once approved, the request is immediately communicated to the supplier for prompt delivery.

The strand management process is then translated into a simulation model by adapting the flow depicted in Figure 2 with the available modules in Arena. The overall model is designed to provide an overview of the Strand raw material management system for post-tensioning at PT XYZ. The strand supply chain at PT XYZ in the simulation, using the Arena program, is divided into two streams: demand management and inventory management. The demand management cycle serves as a trigger for the inventory management stream. Both streams utilize various modules available in Arena, such as Create, Assign, Decide, Signal, Hold, and Dispose.

Before designing the model, an examination of the strand usage data is conducted using historical data from January 2022 to March 2023. By utilizing input analysis, as shown in Figure 4 regarding the production demand distribution, the data follows a Beta distribution.

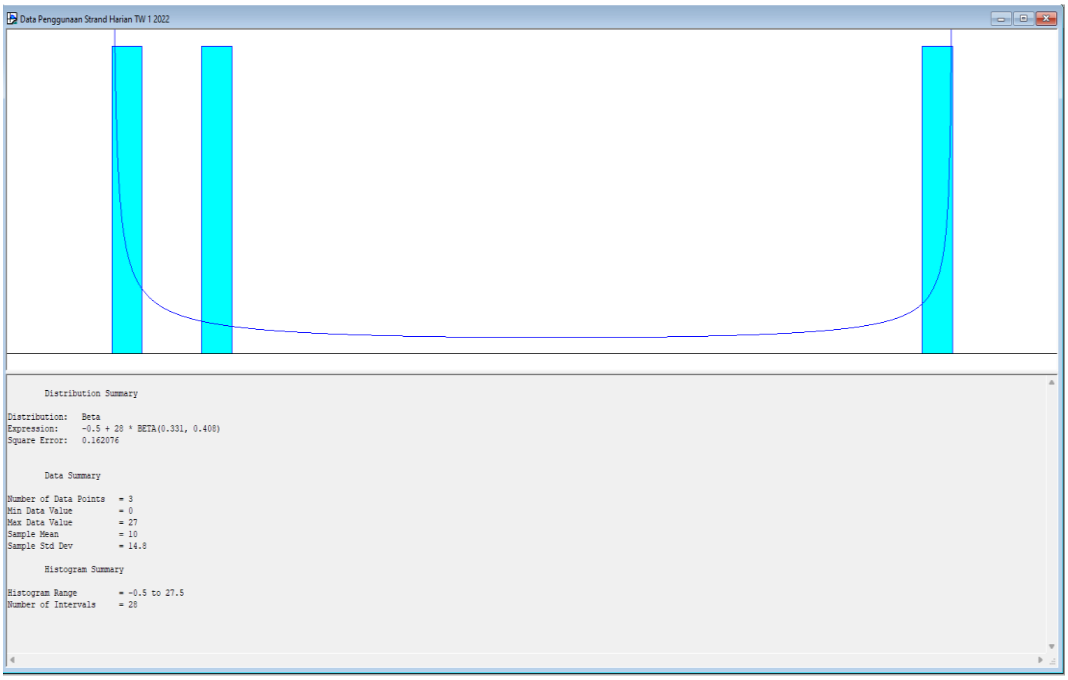

Figure 4. Production Demand Distribution

3.1. Model's Component

a. Create & Entity Modul

Table 2. Create & Entity Modul

Description	Type	Expression	Explanation
Demand For Post Tension	Usage of Strand	-0.5+28 *BETA (0.331, 0.408)Days	To trigger the need for strands based on customer demands

b. Assign Modul

Table 3. Assign Modul

Description	Variable	Value	Explanation
Demand Post Tension	Strand Demand	1	To trigger the demand for strands from the post tension entity
Demand Post Tension	Demand	1	To trigger the demand for post tension works
Permohonan Strand	Supply Strand	1	To trigger the demand for strand procurement
Assign Strand Demand	Demand	-0.5 + 28 * BETA (0.331, 0.408)	To trigger the need for strands based on historical usage of strands
Assign Strand Demand	Strand Demand	1	To trigger the need for strands as raw materials for post tension
Residual	Inventory	Inventory – Strand Demand	To define the inventory position after subtracting the usage of strands
Stop The Delivery	Supply Strand	0	To confirm that no additional strand inventory is required
Procurement Application	Supply Strand	Strand Demand / Order size	To define the required number of shipment cycles for strands
Recivement of Strand	Inventory	Inventory + (Order size * Supply Strand)	To define the inventory position after receiving strands in the number of shipment cycles multiplied by the order size of 30 tons.

c. Decide Modul

Table 4. Decide Modul

Description	Type	Expression
Strand procurement decisions	2-way by Condition	Inventory >= Strand Demand

d. Signal Modul

Table 5. Signal Modul

Description	Signal Value
Post Tension	1

e. Modul Hold

Table 6 Hold Modul

Description	Type
Strand Usage	Wait for Signal

f. Process Modul

Table 7. Process Modul

Description	Type	Unit	Allocation	Value	Explanation
Material Delivery	Standard	Days	Transfer	3	To define the lead time required for strand procurement

3.2. Model Verification and Validation

This study involves a verification process to ensure error absence in upcoming processes, and validation is conducted to assess the model's accuracy compared to the real world. Arena's Check Model feature is used for validation. The simple t-confidence interval method is employed for validation, specifically using the parameter of strand usage. The strand usage data in the system falls within the model's output data interval in Table 8, affirming the model's validity.

Table 8. Model Validation

Description	System (tons)	Mean of Model (tons)	Replication Number	95% Confidence Interval (tons)
Strand usage	6,516	6,833	100	(6,396 ; 7,271)

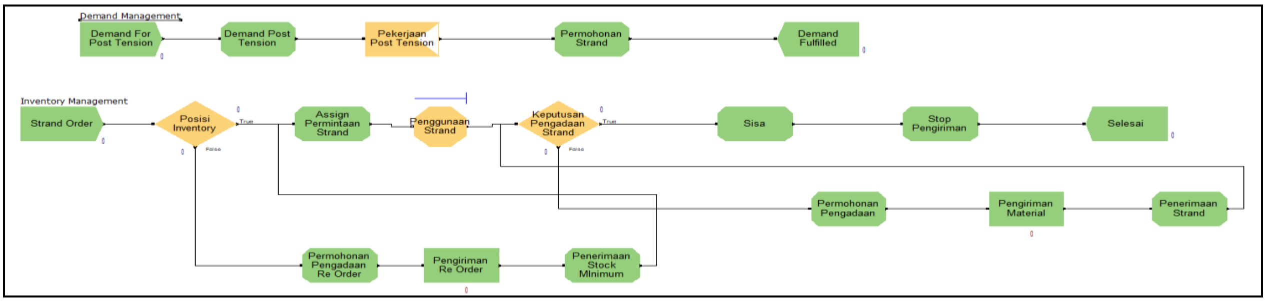

Figure 5. Alternative Scenario Flow

3.3. Scenario Analysis

In the base case model, the determination of reorder points as one of the basis for strand procurement has not been implemented. This leads to fluctuations in strand inventory, where there are periods of excess inventory and periods of stockouts. To address this issue, an additional procurement process based on reorder points is introduced, as shown in Figure 4.

a. Scenario 1: Setting reorder point (5 Tons)

Based on historical data from PT XYZ, the two smallest daily strand usage values are 0 and 3.9 tons. Rounding up these values, a reorder point of 5 tons is determined. The order size remains unchanged at 30 tons for this scenario. The simulation results, as shown in Table 9, indicate a reduction in stockout occurrences from 30 to 5, but the average inventory value increases to 25.153 tons.

b. Scenario 2: Reorder Point (3 Tons) & Order Size (5 Tons)

The second alternative scenario is an extension of Scenario 1. The reorder point in Scenario 2 is determined by rounding down the smallest daily strand usage value, resulting in a reorder point of 3 tons. Adjustments are also made to the order size in Scenario 2, as the results from Scenario 1 show a relatively high average inventory value of 25.153 tons, suggesting that the order size does not match the strand usage. Thus, the order size in Scenario 2 is adjusted based on the difference between the previous order size and the average inventory value from Scenario 1, resulting in a new order size of 5 tons. Scenario 2 yields a decrease in the average inventory value to 4.809 tons without any stockouts.

c. Scenario 3: Reorder Point (5 Tons) & Order Size (10 Tons)

Based on the simulation results of Scenario 2, which resulted in a decrease in the average inventory value by setting the reorder point to 3.9 tons (rounded down from the minimum daily strand usage value) and adjusting the order size based on the difference between the initial quantity (30 tons) and the average inventory value (25.153 tons) to 5 tons. In Scenario 3, further adjustments are made by setting the reorder point to 5 tons (rounded up from 3.9 tons) and increasing the order size to 10 tons. The results show a decrease in the average inventory value to 9.565 tons without any stockouts.

3.4. Differences with the Base Case Model

Table 10 presents the results of paired-t confidence interval testing. From the calculations, it can be observed that all three scenarios show significant differences compared to the base case model. This is indicated by the confidence interval of the differences between the base case model and the alternative scenarios, which do not include zero.

Table 9. Scenario Simulation Result

	Parameter		Simulation Result	
	Reorder Point (ton)	*Order Size* (ton)	Mean of Inventory *Strand* (ton)	*Stock Out* (ton)
Model *Base Case*	0	30	11,693	30
Scenario 1	5	30	25,153	5
Scenario 2	3	5	4,809	0
Scenario 3	5	10	9,565	0

Table 10. The Paired-T Test Result of Scenario and *Base Case Model*

	$Z\ (n)$	*Confidence Interval 95%*	Std Deviation	*Range* (ton)	Result
Model Base Case			10,410		
Scenario 1	-13,256	3,019	15,401	(-17,904 ; -4,649)	Significant
Scenario 2	7,088	1,983	10,117	(0,082; 7,170)	Significant
Scenario 3	2,332	2,214	11,296	(0,267; 2,599)	Significant

3.5. Interpretation

After analyzing the results of the scenarios, it is evident that two of the alternative scenarios, which introduced the additional procurement process based on reorder point compared to the base case model, were able to reduce the inventory level of the strand. However, one scenario did not show a significant decrease in the inventory level, as indicated in Table 9.

Based on Table 9, all three alternative scenarios were able to modify the average inventory level of the strand and reduce the occurrence of stockouts. Scenario 1 resulted in a significant difference compared to the base case model, but it had a higher average inventory level of 25.153 tons compared to the base case model's 11.693 tons. On the other hand, Scenario 2 and Scenario 3 performed better than Scenario 1 by achieving lower average inventory levels below the base case model. Scenario 2 was able to reduce the average inventory level to 4.809 tons, equivalent to a 58.78% reduction, while Scenario 3 achieved an average inventory level of 9.565 tons, equivalent to an 18.19% reduction. Among these two scenarios, Scenario 2 is considered the best as it achieved the lowest average inventory level without causing any stockouts.

3.6. Managerial Implication

Several managerial implications can be derived from the findings of prior research. In the preceding scenario, it was demonstrated that reducing inventory levels can be achieved by integrating a reorder point into the inventory management process, thereby avoiding both surplus and stockouts, as currently observed. The identified optimal reorder point is 3 (three) tons. Additionally, in enhancing inventory management procedures, consideration may be given to adjusting the quantity per shipment to 5 (five) tons. However, altering the order size from 30 (thirty) tons to 5 (five) tons carries implications for existing contracts. This necessitates a renegotiation process to amend clauses in the contract (contract addendum) and adjust indices or the capacity of smaller transport vehicles.

Establishing a reorder point and order size is imperative to preempt delays in post-tension work and anticipate potential claims from the owner. Such occurrences, aside from causing financial setbacks, can tarnish the company's reputation. Furthermore, effective inventory management can forestall the accumulation of substantial inventories over prolonged periods, thereby mitigating the risk of theft and potential losses associated with it.

4. Conclusion

The research focuses on analyzing raw material inventory management, specifically strands for post-tension work, within an Indonesian manufacturing-construction company. The current approach, driven solely by post-tension work demands, lacks comprehensiveness, resulting in unpredictable fluctuations in inventory levels. Utilizing historical data, a base case model was simulated using Arena. However, the analysis reveals suboptimal strand inventory management, characterized by significant fluctuations in average inventory values and occurrences of stockouts in multiple replications.

There are three (3) proposed scenario analyses aimed at resolving the strand inventory management issue. These scenarios are developed by adjusting two (2) key parameters—namely, the reorder point and order size—with the objective of minimizing the average inventory value. In the first scenario, the process flow is modified, and the reorder point for strands is set at 5 (five) tons. However, the outcomes of this scenario reveal that, while successful in preventing stockouts, it does not lead to a reduction in the average inventory value of strands. The second scenario involves establishing the reorder point at 3 (three) tons and adjusting the order size to 5 (five) tons. As for the third scenario, it represents an expansion of the previous scenario, wherein the reorder point is adjusted to 5 (five) tons, and the order size is set at 10 (ten) tons. In contrast to the initial scenario, both of these scenarios effectively reduce strand inventory without inducing stockouts. Based on the significance calculations, positive results are observed, indicating that all scenarios exhibit a noteworthy difference from the base case model.

Therefore, based on the conducted analysis, Scenario 2 emerges as the optimal choice, featuring a reorder point of 3 (three) tons and an order size of 5 (five) tons. This scenario effectively reduces the average inventory value by up to 58%, all while avoiding any instances of stockouts.

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