

Formulation of Raw Material Inventory Model in The Steel Industry

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Abstract. *Suboptimal inventory management can lead to overstocks that increase storage costs or shortages that hamper production. PT XYZ, a manufacturer of automotive components, faces this challenge, especially in the management of steel raw materials. This study aims to develop an inventory management model using the Economic Order Quantity (EOQ) and Mixed Integer Non-Linear Programming (MINLP) approaches to handle uncertainties in steel raw material inventory. This method is complemented by demand forecasting using the ARIMA model to overcome stochastic demand patterns. The results indicate an annual raw material requirement of 809,735 kg, with an optimal inventory cost of Rp 6,943,611,000. Out of four suppliers analyzed, two were selected with raw material allocations of 659,480 kg and 150,255 kg, and reorder points of 2,228 kg and 1,965 kg, respectively. This model reduces the risk of stock shortages and excess inventory, ensures production continuity, and lowers inventory costs.*

Keywords: *EOQ, Inventory, MINLP, ROP, Supplier.*

I. INTRODUCTION

A company, to support a smooth production process, must possess valuable assets, one of which is inventory. Inventory is one of the most expensive resources owned by a company (Hernawati et al., 2020). Inventory refers to resources owned by the company in the form of current assets, used to meet customer demands and support the production process (Wahyu et al., 2021). The company must have policies in place to anticipate the worst-case scenario, which is inventory shortages. Inventory management presents challenges aimed at achieving the lowest possible total handling cost (Rizkya and Fernando, 2021).

Inventory management is a crucial aspect that companies need to master to support successful production processes. It involves the company's ability to regulate and manage the availability of raw materials, semi-finished goods, and finished products, ensuring they are

maintained both during stable market conditions and fluctuations (Laoli et al., 2022). Inventory in a manufacturing company refers to raw materials that are in the production stage and stored for use in subsequent production processes (Lutfiana and Puspitosari, 2020). Raw materials are a key element in the smooth operation of the production process (Hazimah et al., 2020). A company will incur high storage costs if it keeps large quantities of raw materials (Ratningsih, 2021). Conversely, if a company maintains insufficient inventory, it can impact production and even fail to meet customer demands (Wijayanti and Sunrowiyati, 2019). Therefore, a company needs to implement good management practices to fulfill consumer needs and demands, one example being PT XYZ.

PT XYZ was established in 1995 and is a manufacturing company producing spare parts for two-wheel and four-wheel vehicles on a national scale. Based on observations and interviews, PT XYZ faces challenges in effectively planning and controlling its inventory due to demand fluctuations, as shown in Figure 1.

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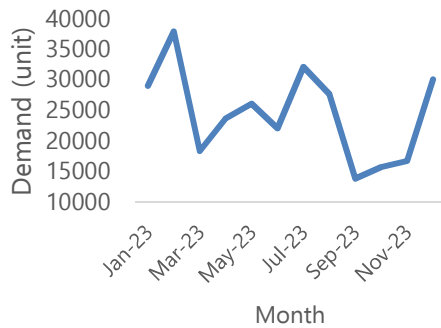


Figure 1 The product demand for steel (units) from February 2023 to January 2024.

The fluctuation in demand for steel-based products from February 2023 to January 2024 has caused PT XYZ difficulty in planning inventory, resulting in stockouts and overstock. Stockouts hinder production, cause opportunity losses, and reduce potential profits, while overstock ties up capital, increases the risk of rust, and leads to weight loss during smelting, which in turn raises the need for raw materials.

In fact, the inventory of raw materials at PT XYZ has not been well planned, especially in purchasing steel from various suppliers, leading to mismatches in order quantity and timing. This has resulted in excess or insufficient stock during certain periods. Therefore, an optimal inventory control strategy is needed to align orders with demand, reduce the risk of shortages, and minimize costs.

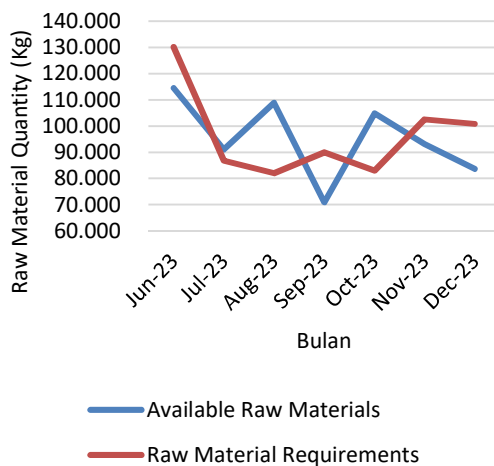


Figure 2 The Raw Material Requirements (Kg) and Steel Stock in the Warehouse for the June – December 2023 Period.

PT XYZ has four raw material suppliers for steel, each with limitations in fulfilling demand. To avoid stockouts and overstocks that can disrupt production and increase inventory costs, the company needs to optimize its ordering process while considering uncertainties such as lead time, price, delivery capacity, and inventory costs. This uncertainty management strategy is crucial to ensure a smooth and efficient supply chain.

Based on the problem description above, this research focuses on improving raw material management by optimizing orders from each supplier and minimizing inventory costs. The main objective of the research is to ensure that the company can meet customer demand more effectively while minimizing inventory costs. By forecasting and managing the uncertainties related to raw material inventory, this study aims to address these uncertainties through the formulation of a mathematical model that determines the optimal order level from each supplier, as well as reducing storage costs to efficiently handle fluctuations in demand and supply.

II. RESEARCH METHOD

This research begins with a literature study and observation to identify the issues at PT Sinar Agung Selalu Sukses. The next step is to formulate the problem to determine the focus of the research. The literature review is conducted by analyzing previous studies and relevant theories. Subsequently, data collection is carried out by gathering both primary and secondary data, which will be used for data processing. The data is then processed using forecasting to obtain the raw material requirements for the following year, creating mathematical formulas to calculate the order quantity from each supplier, finding the minimum cost using the economic order quantity method, determining safety stock to reduce the risk of stockouts and overstock, and calculating the reorder point to identify the ordering point. This process will lead to answers to the research problem formulation. The research stages can be seen in Figure 2.

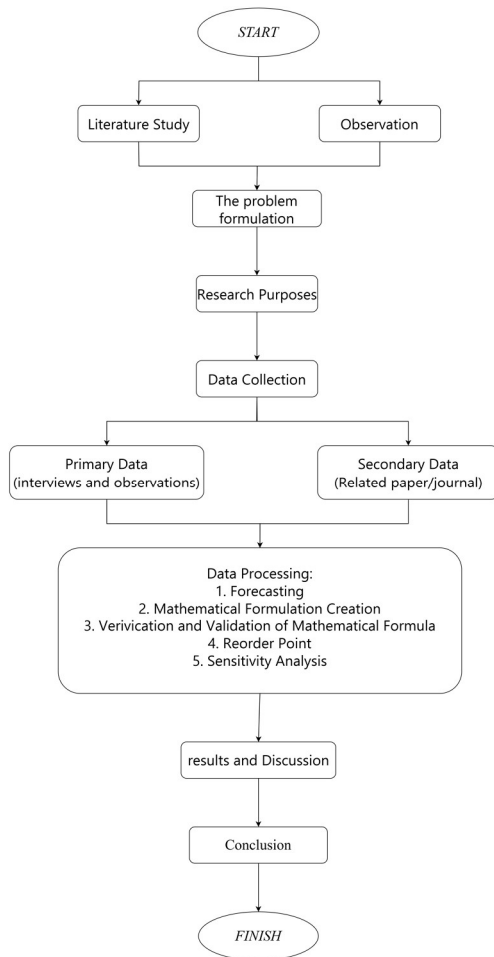


Figure 3 Research Flow

The object of this research is the inventory management control of raw materials at PT XYZ. This is due to indications of stockout and overstock issues that have caused disruptions in the production process and resulted in high inventory costs. This study collects two types of data: primary data and secondary data. The primary data is obtained through direct interviews to identify issues in the production process, as well as observations at the company to map problems related to stockouts and overstock of raw materials. Meanwhile, secondary data is collected through a literature review as a reference or basis for the research.

In general, the data analysis techniques carried out in this study begin with demand forecasting to determine raw material requirements, mathematical inventory modeling, and sensitivity analysis. Forecasting is performed

to plan future needs by selecting the appropriate method based on historical data patterns to minimize forecasting errors(Alejo-Reyes et al. 2023) (Famelga Clea Putri 2023)[20] [21]. After obtaining demand forecasts, the next step is to average them to get a more stable view. The mathematical model uses the Mixed Integer Non-Linear Programming (MINLP) method to determine the minimum inventory cost by combining the Economic Order Quantity (EOQ) equation (Dutta and Kumar n.d.) [22], and safety stock to minimize inventory costs (Mubin, Syahril, and Rosiani 2021) [23]. Determining the reorder point ensures timely reordering to prevent stockouts (Piranti and Sofiana 2021)[24]. Sensitivity analysis is conducted to identify tolerable changes in key factors to achieve an optimal solution (Ahmad 2020)(Maysofa and Umam Syaliman n.d.) [25] [26].

III. RESULT AND DISCUSSION

3.1 Research Data

3.1.1 Raw Material Demand Data for Steel (Kg)

Demand represents the total quantity of goods or services requested by consumers at a specific price over a certain period (Venny and Asriati 2022) (Venny & Asriati, 2022). This study examines the demand for steel raw materials based on the level of demand for steel products over the past three years. The demand for steel raw materials is calculated based on the products (units), which are then multiplied by the amount of steel material required for each product. This results in raw material demand data, as presented in Table 1, which can be used to understand and analyze the patterns in the generated data.

Table 1 Raw Material Demand Data for Steel (Kg) from January 2021 to December 2023

Month	Period	Demand (kg)
January 2021	1	177.868
February 2021	2	155.489
March 2021	3	171.777
April 2021	4	161.435
May 2021	5	176.127
June 2021	6	146.935

Month	Period	Demand (kg)
July 2021	7	186.794
Agust 2021	8	151.960
September 2021	9	190.280
October 2021	10	136.272
November 2021	11	191.511
December 2021	12	153.618
January 2022	13	165.993
February 2022	14	135.627
March 2022	15	151.391
April 2022	16	131.125
May 2022	17	147.721
June 2022	18	122.689
July 2022	19	146.722
Agust 2022	20	118.537
September 2022	21	110.773

Month	Period	Demand (kg)
October 2022	22	133.683
November 2022	23	149.965
December 2022	24	124.345
January 2023	25	103.555
February 2023	26	103.714
March 2023	27	99.931
April 2023	28	106.991
May 2023	29	91.405
June 2023	30	130.128
July 2023	31	86.874
Agust 2023	32	82.048
September 2023	33	89.995
October 2023	34	83.051
November 2023	35	102.566
December 2023	36	100.826

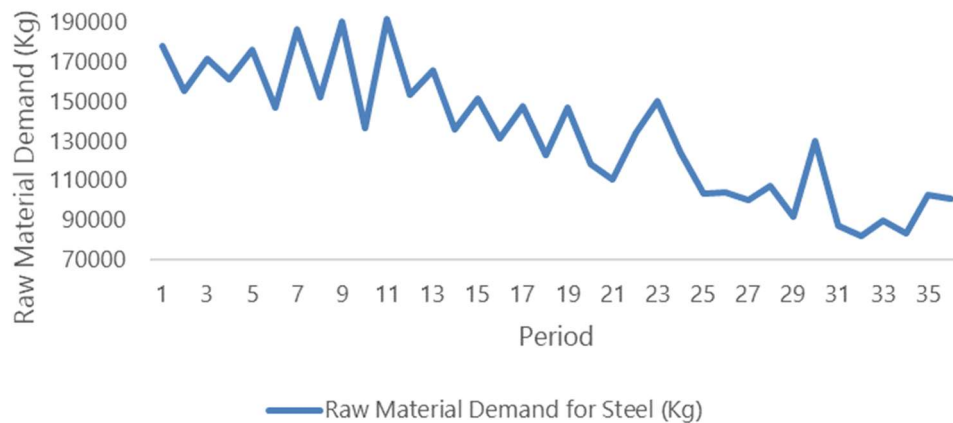


Figure 4 Graph of Raw Material Steel Demand (Kg) from January 2021 to December 2023

Figure 4 shows the raw material demand pattern for steel at PT XYZ over the past three years, indicating a downward trend with irregular monthly fluctuations, reflecting the non-stationary nature of the data. This instability is marked by inconsistent value changes over time, without a steady average or clear seasonal pattern.

3.1.2 Suppliers Data

PT XYZ collaborates with four suppliers to meet its steel raw material needs. However, the ordering system, which only places orders when stock runs out, results in a high order frequency. This increases inventory operational costs as the company has to place repeated orders to ensure smooth production. The supplier data is shown in Table 2.

Table 2 Data Supplier Raw Material Steel PT XYZ

Suppliers	Lead Time (day)	Shipping Capacity/year (kg)	Capacity/ship (kg)	Price (IDR)
Supplier 1	1	659.480	7.000	7.500
Supplier 2	2	412.040	9.500	8.000

Suppliers	Lead Time (day)	Shipping Capacity/year (kg)	Capacity/ship (kg)	Price (IDR)
Supplier 3	4	467.200	8.600	7.800
Supplier 4	3	472.020	10.000	7.600

3.1.3 Other Supporting Data

The optimization model is supported by key data, including an ordering cost of IDR 25.000 per transaction, storage cost of IDR 100.000 per day for handling raw materials, and a target service level of 80% as the basis for calculating safety stock. This data ensures that each variable reflects the actual operational conditions and supports efficient inventory management.

3.2 Forecasting

Demand forecasting for raw materials was

conducted using data from January 2021 to December 2023 (36 periods) with the moving average, exponential smoothing, and ARIMA methods to handle non-stationary data fluctuations. These three methods were chosen because they can accommodate demand instability. The forecasting results were compared based on error values to determine the most suitable method for the available data pattern. The results of the forecasting from the three methods used are as follows.

Table 3 The Forecasted Results (Kg) of Raw Material Steel for PT XYZ

Month	Period	Moving Average	Exponential Smoothing	ARIMA
January 2025	1	91697	97770	82108
February 2024	2	93627	97770	79448
March 2024	3	94353	97770	76788
April 2024	4	96614	97770	74128
May 2024	5	95424	97770	71468
June 2024	6	94343	97770	68808
July 2024	7	94872	97770	66148
Agust 2024	8	95121	97770	63488
September 2024	9	95275	97770	60827
October 2024	10	95007	97770	58168
November 2024	11	94924	97770	55508
December 2024	12	95040	97770	52848
Sum		984.905	1.040.268	905.872

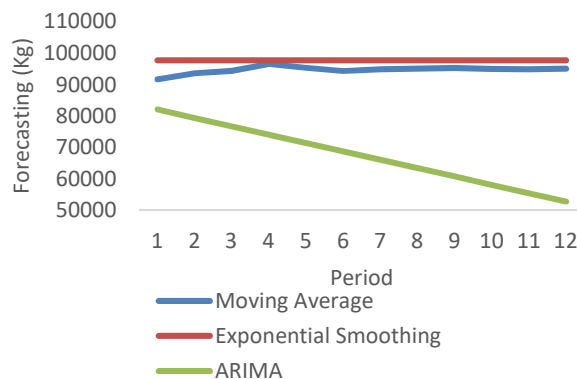


Figure 4 Forecasting Graph of Raw Material Steel (Kg) PT XYZ

The forecasting results are evaluated based on the error rate, where a lower error value indicates better forecasting accuracy (Amallynda and Wicaksono, 2024). Table 4 presents a summary of the errors from each method to assess the forecasting performance.

Table 4 Recap of Raw Material Forecasting Errors at PT XYZ

No	Method	MAE	MSE	MAPE
1	Moving Average	17.872,93	401.453.905,72	14,56%
2	Exponential Smoothing	17.257,97	397.669.841,10	13,42%
3	ARIMA	13.602,07	265.031.573.26	10,17%

The ARIMA method produces the most accurate predictions compared to Moving Average and Exponential Smoothing, with MAE, MSE, and MAPE values of 13,602.07, 265,031,573.26, and 10.17%, respectively. The ARIMA forecast for the period from January to December 2024 shows a gradual decline from 82,108 kg in January to 52,848 kg in December, with a total forecast of 905,872 kg. Therefore, ARIMA is recommended as the best forecasting method in this study.

This forecasting is conducted to help the company determine the raw material needs for steel over the next year in alignment with demand and production trends. With accurate forecasting, the company can optimize raw

material procurement, reduce the risk of stock shortages or surpluses, and enhance operational efficiency. This needs assessment also plays a role in more strategic production planning, ensuring smooth manufacturing processes and supporting overall business sustainability.

3.3 Mathematical Formulation

3.3.1 Notation

Notation refers to symbols or representations used to express elements in a mathematical model. In this study, the developed mathematical model includes index notation, parameters, and decision variables designed to support the cost optimization analysis of inventory. The notations used are presented in Table 5.

Table 5 Mathematical Model Notation

Category	Notation	Information
Index	i	Supplier (1...4)
	D	Demand
	Z	Service score
Parameter	σ	Standard deviation of demand
	P	Price of raw steel materials (kg)
	S	Ordering cost
	LT	Lead time for raw material ordering (day)
	H	Holding cost
	K	Supplier's shipping capacity in one year (kg)
	C	The supplier's delivery capacity per shipment (kg)
	SS	Safety stock per year (kg)
Decision Variables	x	Total order quantity per supplier
	y	1 if the supplier is used, 0 if the supplier is not used

3.3.2 Mathematical Model

The mathematical model for optimizing inventory costs at PT XYZ includes ordering, holding, purchasing, and safety stock costs. The objective of this model is to determine the optimal order quantity and calculate the total cost, which comprises holding, purchasing, and safety stock costs from each supplier. All cost

components are integrated into a Mixed Integer Nonlinear Programming (MINLP) model, designed to minimize total inventory costs while considering relevant constraints based on the company's inventory system conditions. The developed mathematical model is as follows.

Objective Function:

$$\text{Min Cost} = \left(\sum i (\text{ordering cost} + \text{purchasing cost} + \text{safety stock cost}) \right) + \text{holding cost}$$

$$\text{Min Cost} = \left(\sum i \left(\frac{d}{EOQ} S + dP + Z\delta\sqrt{LTP} \right) \right) + H$$

$$\text{Min Cost} = \left(\sum i \left(\frac{d}{\sqrt{\frac{2 \times d \times S}{H}}} S + dP + Z\delta\sqrt{LTP} \right) \right) + H$$

$$\text{Min Cost} = \left(\sum i \left(\frac{x}{\sqrt{\frac{2 \times x \times S}{H}}} Sy + xPy + Z\delta\sqrt{LTPy} \right) \right) + H$$

Subject to:

1. The total order quantity from each supplier must meet the annual demand.

$$\sum x_i \geq D$$

2. The orders from each supplier do not exceed the supplier's delivery capacity within a year

$$x_i \leq Ky$$

3. The minimum order quantity from the supplier must be less than the delivery capacity per shipment from the supplier

$$\sqrt{\frac{2 \times x \times S}{H}} \leq Cy$$

4. Multiple suppliers are used.

$$\sum i \geq 1$$

5. y is a binary variable where y = 0 or y = 1. If y = 0, the supplier is not used, and if y = 1, the supplier is used to meet the company's needs.

$$y = \{1,0\}$$

6. The variable x must be non-negative.

$$x_i \geq 0$$

This mathematical model is designed to minimize inventory costs by determining the optimal suppliers for sourcing steel raw materials and the quantity each supplier should deliver, in accordance with the company's requirements.

3.3.3 Verification and Validation of the Mathematical Model

The verification and validation of the mathematical model are conducted by comparing the inventory cost calculations generated by

Lingo software with recorded inventory cost data from the 2021 to 2023 period. This step aims to evaluate how accurately the developed mathematical model represents the company's real conditions. By comparing these results, the model's alignment with the company's operational reality can be assessed, ensuring its validity and reliability as a decision-support tool for inventory management.

Table 6 Verification and Validation of the Mathematical Model

Year	Company Inventory Cost (IDR)	Lingo Inventory Cost (IDR)	Percentage Error	Absolute percentage Error
2021	15.599.836.000	17.365.490.000	-11%	11%
2022	14.056.899.000	14.175.990.000	-1%	1%
2023	9.511.094.500	10.141.620.000	-7%	7%
Mean Absolute Percentage Error (MAPE)				6%

Based on Table 6, the validation results of the company's inventory costs with LINGO optimization for 2021-2023 show varying differences, with a deviation of 11% in 2021, 1% in 2022, and 7% in 2023. The LINGO optimization model demonstrates good accuracy, as reflected in the Mean Absolute Percentage Error (MAPE) of 6%, indicating a low error rate and making it a reliable tool for helping the company manage inventory costs efficiently (Amallynda and Wicaksono, 2024).

3.3.4 Mathematical Model Output

The mathematical model that has been designed is translated into the Lingo programming language and executed to optimize inventory costs using the company's data. After solving, the model produces the optimal inventory cost and determines the order quantity to be placed with each supplier, as well as which suppliers should be used to meet the company's demand. The results of the model solve are shown in Figures 6 and 7.

```
Local optimal solution found.
Objective value:           0.6943611E+10
Objective bound:           0.6943611E+10
Infeasibilities:            0.000000
Extended solver steps:      26
Total solver iterations:    1128
Elapsed runtime seconds:    0.28

Model Class:               MINLP
```

Figure 5 The Result of the Lingo Solver

Based on Figure 6, the results from the Lingo model show that the optimal solution is achieved with a total inventory cost of 0.6943611E+10, equivalent to IDR. 6,943,611,000. No infeasibility was found in the model, indicating that all constraints have been properly satisfied. The optimization process itself required 1128 iterations and demonstrates the MINLP (mixed integer nonlinear programming) mathematical model, which reflects a combination of continuous and binary decisions to optimize costs while considering all parameters and constraints.

```
X( 1)      659480.0
X( 2)      0.000000
X( 3)      0.000000
X( 4)     150255.0
Y( 1)      1.000000
Y( 2)      0.000000
Y( 3)      0.000000
Y( 4)      1.000000
```

Figure 6 The Result of the Lingo x and y

The optimal solution for fulfilling the annual demand of 809,735 kg involves only supplier 1 and supplier 4, with purchase amounts of 659,480 kg and 150,255 kg, respectively, while suppliers 2 and 3 are not used ($Y(2)=0$, $Y(3)=0$).

The solution demonstrates the most efficient combination of ordering, storage, raw material purchasing costs, and safety stock. Suppliers 1 and 4 are chosen due to their competitive pricing, high shipping capacity, and efficient lead time, with supplier 1 offering the lowest price per kg (IDR 7,500) and the fastest lead time (1 day), while supplier 4 complements the needs with large shipping capacity and a slightly higher price (IDR 7,600). Suppliers 2 and 3 are not selected due to higher prices, lower capacities, and longer lead times, resulting in higher costs and increased safety stock needs. The model is valid and identifies the optimal solution with no infeasibilities.

3.4 Reorder Point

The reorder point (ROP) calculation for each supplier indicates the point at which reordering should be done to avoid running out of raw materials in production. Based on the inventory model used, the ROP values for each supplier are 2,228 kg for UD Doa Ibu and 1,965 kg for CV Berkah Makmur. This means the company should reorder raw materials from each supplier at the corresponding ROP to ensure smooth production without experiencing stockouts. Determining the correct ROP is crucial to ensure efficient inventory management and reduce the risk of production delays. The reorder point graphs for each supplier can be seen in Figures 7 and 8, respectively.

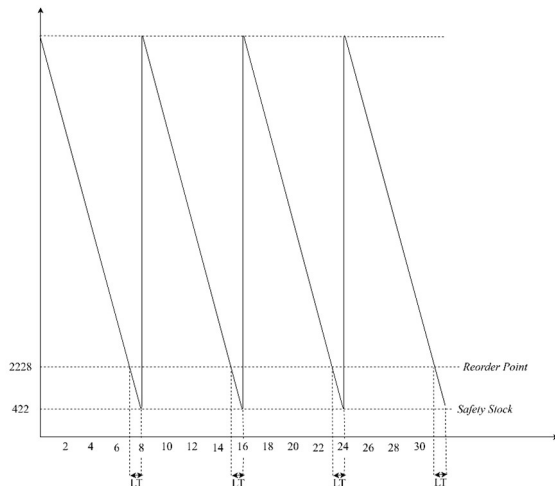


Figure 7 ROP Graph of Supplier 1

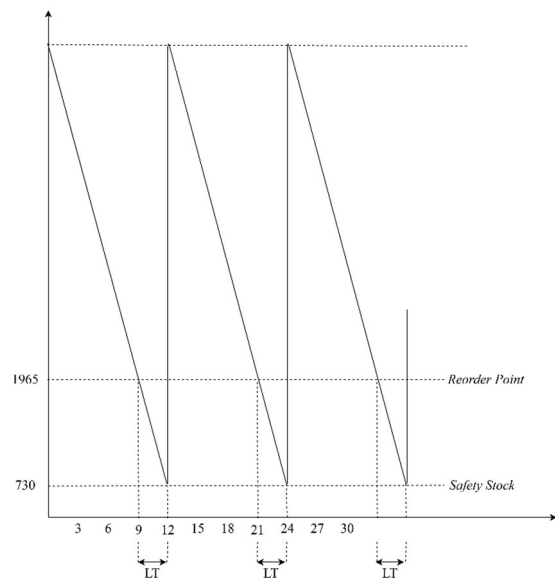


Figure 8 ROP Graph of Supplier 4

3.5 Sensitivity Analysis

3.5.1 Model Optimization

The optimization model uses real data from the company's forecasting as the primary basis for sensitivity analysis. This data reflects the company's actual operational conditions, providing a more relevant and applicable perspective for decision-making. The optimization process produces an output shown in Figure 4.8, where the most optimal inventory cost is IDR 6,943,611,000 (0.6943611E+10). This result represents the best solution based on the parameters set using the company's real data.

Sensitivity analysis is used to assess the impact of changes in specific variables on the optimization results, ensuring that the solution is not only optimal but also resilient to uncertainty in a business context. This process involves altering parameters by a certain percentage from their initial values, including -5%, -10%, -15%, -20%, -25%, +5%, +10%, +15%, +20%, and +25%. The selection of these change scenarios is based on the approach used in Wijaya and Titania (2021) providing a strong foundation for exploring the potential impacts of parameter changes on the optimal solution.

3.5.2 Sensitivity Analysis

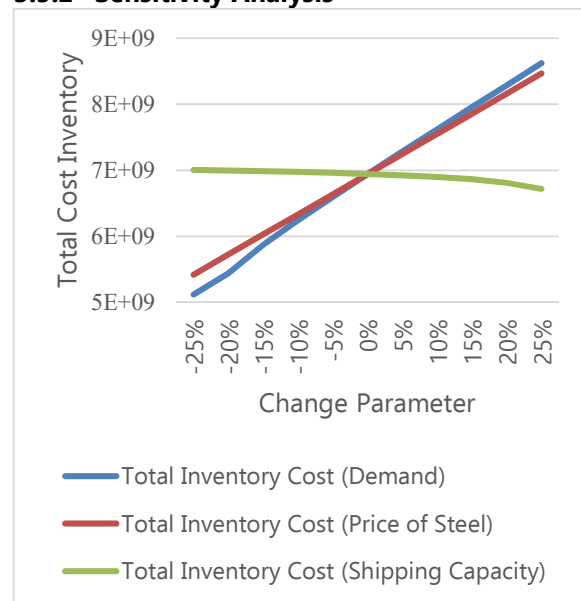


Figure 9 Comparison of Sensitivity Analysis

Sensitivity analysis on demand, raw material prices, and shipping capacity reveals different patterns of impact on total inventory costs. Demand changes are highly sensitive as they directly affect raw material needs and determine whether suppliers can meet the company's full demand. Additionally, changes in raw material prices are also highly sensitive, as higher prices lead to greater inventory costs. Meanwhile, shipping capacity has a significant but more controlled impact, as increased shipping capacity with lower costs can reduce overall inventory costs. In this study, sensitivity analysis helps the company understand the factors most influential on inventory costs, enabling better decision-

making in inventory management. Furthermore, this analysis allows the company to optimize supplier selection by considering existing uncertainties, thus improving cost efficiency, supply chain stability, and ensuring better raw material availability to meet customer demand.

IV. CONCLUSION

This study successfully developed a mathematical inventory management model using the EOQ approach combined with MINLP, supported by ARIMA forecasting to predict the annual raw material demand of 809,735 kg. The optimization results showed a reduction in total inventory costs to IDR 6,943,611,000, with the selection of two efficient suppliers, Supplier 1 and Supplier 2, based on their delivery capacity, lead time, and cost, with allocations of 659,480 kg and 150,255 kg, respectively. The ROP set for each supplier is 2,228 kg and 1,965 kg. This model effectively optimizes inventory, reduces costs, and minimizes the risks of overstock and stockouts, while enhancing cost efficiency, production continuity, and product availability across the complex supply chain. The ARIMA forecasting also allows for more accurate raw material demand anticipation, supporting the optimal supplier selection strategy.

The implementation of this model has a significant impact on operational efficiency, especially in reducing the risk of overstocks and shortages that previously hampered the production process. In addition, the calculation of Economic Order Quantity (EOQ), safety stock, and reorder points tailored to each supplier, ensures the smooth production process and optimization of inventory costs. This research provides important implications for inventory management in the manufacturing sector. By combining accurate forecasting and inventory optimization, companies can meet customer demand more effectively while minimizing operational costs. In the future, similar research can be further developed by integrating digital technologies such as IoT for real-time inventory monitoring, considering supply chain risk factors, and adopting a multi objective approach that includes

sustainability and environmental aspects. The results of this study are expected to serve as a strategic guide for other companies in facing inventory management challenges.

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