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Spare Parts Classification for CO_2 Compressor Using Multi-Criteria and SES Forecasting at PT PIM

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ABSTRACT

PT Pupuk Iskandar Muda (PIM), a subsidiary of PT Pupuk Indonesia (Persero), plays a pivotal role in supporting national food security through the reliable operation of its fertilizer plants. Effective spare parts inventory management is crucial to ensure uninterrupted plant operations. However, challenges arise due to the high volume of spare parts managed and the intermittent or lumpy nature of demand. Inefficient inventory management has led to stockpiling of certain items and shortages of frequently used materials. This study aims to classify spare parts used in the CO_2 Compressor of the PIM-1 Plant using a multi-criteria analysis method, considering critical factors related to maintenance and logistics. The classification categorizes spare parts into three groups: high, medium, and low. Out of 20 spare parts analyzed, 18 items were classified as high priority (stock items), while 2 items were classified as low priority (non-stock items). Forecasting for the 18 high-priority items was conducted using three methods: Single Exponential Smoothing (SES), Syntetos-Boylan Approximation (SBA), and Croston. The forecasting errors were evaluated using the Mean Absolute Deviation (MAD). The results indicated that SES yielded the smallest error, with an average MAD of 2.15, compared to SBA (2.24) and Croston (2.37). Implementing this approach resulted in a 22% reduction in inventory costs, decreasing the estimated inventory cost for 2023 from IDR 3.428 billion to IDR 2.681 billion. This demonstrates the importance of applying appropriate methods in spare parts management to enhance operational efficiency and support the company's objectives.

Keywords: *inventory optimization, maintenance planning, Spare parts inventory, multi-criteria analysis, forecasting, Single Exponential Smoothing (SES).*

INTRODUCTION

Parts inventory management is essential for companies that rely on sustainable machinery or equipment (Kuroki, 2018). This is because the reliability of industrial equipment decreases over time as its usage age increases. At a certain point, the equipment must be maintained or even replaced (Jackson & Pascual, 2008). One form of equipment maintenance is the immediate replacement of damaged components to prevent prolonged operational downtime. Shutting down equipment can result in wasted costs, which is why spare parts inventory is crucial.

The number of spare parts in a medium-scale engineering business may reach tens of thousands, while in large-scale chemical plants, it can amount to hundreds of thousands. Under these conditions, identifying the appropriate stock control strategy for each spare part using human judgment alone becomes challenging. Therefore, inventory management is a major challenge (Hu et al., 2017; Bacchetti & Saccani, 2012). From the perspective of inventory management, it is recognized that the management of spare parts differs from other manufacturing supplies, such as in-process goods and finished products, in several ways (Porras & Dekker, 2008; Garg & Deshmukh, 2006). According to Kennedy et al. (2002), there are two main differences between these types of inventory in terms of functionality and inventory management policies. Specifically, the level of spare parts inventory is largely determined by how equipment is used and maintained (Lengu et al., 2020; Sharma et al., 2011; Bacchetti et al., 2013). This reinforces the need for more advanced, data-driven approaches in spare parts classification and replenishment.

Several aspects contribute to the complexity of spare parts demand and management, namely the high number of spare parts managed and the presence of *intermittent* or *lumpy demand*. *Intermittent demand* refers to demand that occurs at irregular intervals and with highly variable quantities, while *lumpy demand* describes demand with uneven timing and fluctuating quantities (Bacchetti & Saccani, 2012).

Spare parts management at PT Pupuk Iskandar Muda is handled by the Department of Planning, Receipt, and Warehousing, where the number of material stock numbers managed is 19,262 items, of which 80%, or 15,445 items, are spare parts. PT Pupuk Iskandar Muda has implemented the *System Application and Product in Data Processing* (*SAP*) *Material Management* (*MM*) Module for spare parts management. Based on the stock management method in the MM module, spare parts are divided into two categories of *MRP* (*Material Requirement Planning*) Type: *V1* (*Replenish stock to maximum*) and *PD* (*Purchase by order*).

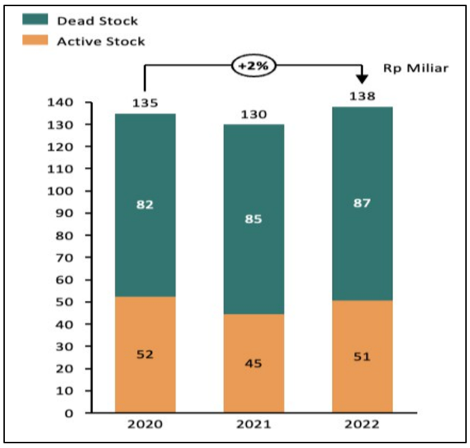

Figure 1. Spare Parts Inventory Profile

Source : SAP Inventory Report of PT Pupuk Iskandar Muda (2020 to 2022)

Even though *SAP* has been implemented, the management of spare parts inventory at PT Pupuk Iskandar Muda can be considered ineffective. This is evident in Figure 1.1, which shows the number of *dead stock* parts continuing to increase each year. In the company's accounting records, *dead stock* material is classified as non-current assets and will be subject to provision fees according to the provision rate set by management and shareholders. Essentially, the provision costs incurred are direct losses that reduce the company's generated profits.

Ineffective inventory management leads to stockpiling of certain materials and shortages of other frequently used materials. The lack of proper classification of spare parts and the absence of formulas for calculating stock requirements cause management difficulties in prioritizing purchases. The *SAP* module used also does not accommodate collective calculation of stock needs, so determining inventory quantities is still performed manually based on previous usage history. Therefore, to avoid shortages of spare parts, management decided to purchase every spare part without first determining which items are critical, resulting in waste.

Previous research related to the classification of spare parts was conducted by Molenaers et al. (2012) on international companies in the petrochemical industry. In their research, Molenaers et al. classified spare parts based on the criteria of part criticality. The determined criteria were then analyzed and categorized using the *VED* (*Vital, Essential, Desirable*) scale. The criteria consist of three attributes: replenishment time, number of potential suppliers, and availability of technical specifications. The result of this study is a parts criticality diagram that combines the level of criticality and logistics characteristics. Molenaers et al. further determined the level of criticality in four categories: high (1), medium (2), low (3), and none (4).

Bacchetti et al. (2010) also developed a multi-criteria method for classifying parts. This research was tested on manufacturing companies and produced 12 criteria, including sales cycle phase, response lead time to customers, number of orders, demand frequency, part criticality, and part value. The results of the spare parts classification were then proposed for use in the demand and inventory management methods of the test companies.

In addition to parts classification, another important aspect of spare parts management is forecasting parts demand. As previously explained, the characteristics of spare parts demand are very difficult to predict, as requests are not only random but also frequently have zero demand values. However, many studies have attempted to forecast these *intermittent* parts items.

In this study, a data sample of 20 spare parts used in the *CO_2 Compressor* equipment of the *PIM-1 Factory* (Equipment Number 52-GB102AB) was selected. Based on the classification of spare parts using a multi-criteria analysis method, out of the 20 spare parts items, 18 were categorized as high (material inventory needed) and 2 as low (non-stock), where for the low (non-stock) category, purchases will be made as needed without maintaining inventory.

Research by Syntetos et al. (2015) compared the *Croston* method and the *Syntetos-Boylan Approximation* (*SBA*), while Willemain et al. (2004) compared the exponential smoothing method, the Croston method, and the bootstrap method. The exponential smoothing method itself was the first forecasting method applied to intermittent data. In this study, three forecasting methods were used: *Single Exponential Smoothing* (*SES*), *Syntetos-Boylan Approximation* (*SBA*), and the *Croston* method. The results of forecasting error tests, as measured by the *Mean Absolute Deviation* (*MAD*), showed that the SES method had the lowest error value, with an average of 2.15, while the error values for the SBA and Croston methods were 2.24 and 2.37, respectively.

This study also compared estimated cost requirements by contrasting the results of forecasting calculations using the *Single Exponential Smoothing* (*SES*) method with the existing method currently used at PT Pupuk Iskandar Muda. From these calculations, a difference of 28% in estimated material cost requirements was obtained: for 18 stock items, a cost of IDR 2.681 billion is needed, whereas the existing method requires a total cost of IDR 3.428 billion.

METHOD

This research was carried out at PT Pupuk Iskandar Muda (PT PIM), which is located in Dewanata District, North Aceh Regency, Aceh Province. PT PIM is a company engaged in the field of petrochemicals. This research was conducted from October 2022 to December 2022 in the work unit of the Department of Planning, Receipt & Warehousing.

Figure 2. Location of PT Pupuk Iskandar Muda
Source: https://www.google.co.id/maps

The data collection stage is an important step in this study to obtain the information needed in the classification of parts and forecasting of inventory needs. This stage includes, among others:

The data used in this study are primary data and secondary data, both quantitative and qualitative.

a. Primary Data: Is data obtained directly from the field through observation, interviews, and documentation studies.
b. Secondary Data: Is the data obtained from the SAP system used by PT Pupuk Iskandar Muda, such as SAP PM (Plant Maintenance) and SAP MM (Materials Management) and monthly reports.

The data collection techniques in this study will be carried out by means of documentation studies, direct observation and interviews.

a. Documentation Study: Access historical data on parts usage from SAP systems, including information on frequency of use, lead time, and cost.

b. Direct Observation: Conduct direct observation of the operation of the CO_2 Compressor to understand the needs of the parts in a contextual manner.
c. Interviews: Conduct interviews with technicians and maintenance staff to obtain additional information regarding the use and requirements of parts.

The data needed for this research are as follows.

a. Spare parts usage frequency data: Number of spare parts usage per year
b. Lead Time Data: The time it takes to acquire parts after ordering
c. Part Cost : Cost of purchasing spare parts
d. Critical equipment data: Information about the level of critical parts to operations.

The data collection procedure is as follows:

a. Parts Identification: Specifies the list of parts used on the CO_2 Compressor.
b. Historical Data Collection: Collects data on the use of parts over a specific period of time from SAP PM and MM systems.
c. Observation and Interview: Conduct observations and interviews to obtain contextual information regarding the use of parts.
d. Data Analysis: Analyze the data that has been collected for parts classification and inventory requirement forecasting.

The data processing method in this study consists of two main stages: classification of parts using the Multi-Criteria Analysis method, forecasting of parts needs using the Single Exponential Smoothing (SES), Syntetos Boylan Approximation (SBA) and Croston methods, and calculation of error forecasting using the Mean Absolute Deviation (MAD) method.

RESULTS AND DISCUSSION

Demand Forecasting Calculation

The demand forecasting calculation uses three methods, namely Single Exponential Smoothing (SES), Syntetos Boylan Approximation (SBA) and Croston. Based on the results of the classification of spare parts by the multi-criteria analysis method, out of the 20 sample items of spare parts analyzed, only 18 items were included in the high category. While the other 2 items are in the low category. Therefore, according to the recommendations and classification of spare parts in table 3.3, the high category is the category of spare parts whose availability in the warehouse is needed while the low category of the availability of goods in the warehouse is not needed and can be carried out a purchase by order (non-stock item) system. Therefore, the calculation of forecasting needs was only carried out for 18 items in the high category.

Forecasting Calculation with Single Exponential Smoothing Method

The following are the results of the calculation of forecasting the needs of CO2 Compressor parts for the PIM-1 Factory for three years (2023 – 2025) using the Single Exponential Smoothing (SES) method.

Table 1. Results of Forecasting Needs by Single Exponential Smoothing (SES) Method

No. Material	Spare Parts Specification	Period *Forecasting*		
		2023	2024	2025
		A Need for Help		
6138949	RING,PISTON:KOBE KM-2 COMPR, 2ND STG	1	1	0
6138950	RING,PISTON:KOBE KM-2 COMPR, 1ST STG	0	0	0
6138937	RING,BREAKER; 88.9X120.7X15.6MM; BRZ/SS	1	1	0
6138942	RING,BACK-UP:89.2X120.7X6.3MM; BRZ/SS	0	0	0
6138953	VALVE ASSY:DAMPED; KOBE; COMP, 1ST SUC	0	0	0
6138954	VALVE ASSY:DAMPED; KOBE; COMP, 1ST DIS	0	0	0
6138955	VALVE ASSY:DAMPED; KOBE; COMP, 2ND SUC	0	0	0
6138959	VALVE ASSY:DAMPED; KOBE; COMP, 2ND DIS	0	0	0
6138961	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1	1	0
6138956	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	0	0	0
6138958	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	0	0	0
6138962	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1	0	0
6138960	SPRING,HELICAL:VALVE; KOBE KM-2 COMPR	11	8	5
6139699	1ST CYLINDER LINER:KOBE; COMPR	0	0	0

No. Material	Spare Parts Specification	Period *Forecasting*		
		2023	2024	2025
		A Need for Help		
6139710	ROD,PISTON:ASSY; 1ST-STG; KOBE; COMP	0	0	0
6139709	ROD,PISTON:ASSY; 2ND-STG; KOBE; COMP	0	0	0
6143118	PACKING ROD ASSY:2ND-STG; KOBE; COMP	0	0	0
6152255	VALVE,BLEED:KOBE KM-2 COMPR	0	0	0

Forecasting Calculations with the Syntetos Boylan Approximation Method

The following are the results of the calculation of forecasting the need for CO2 Compressor parts at the PIM-1 Factory for three years (2023 – 2025) using the Syntetos Boylan Approximation (SBA) method.

Table 2. Results of Forecasting Needs with the Syntetos Boylan Approximation (SBA) Method

No. Material	Spare Parts Specification	Period *Forecasting*		
		2023	2024	2025
		A Need for Help		
6138949	RING,PISTON:KOBE KM-2 COMPR, 2ND STG	1	1	1
6138950	RING,PISTON:KOBE KM-2 COMPR, 1ST STG	0	0	0
6138937	RING,BREAKER; 88.9X120.7X15.6MM; BRZ/SS	1	1	1
6138942	RING,BACK-UP:89.2X120.7X6.3MM; BRZ/SS	2	2	2
6138953	VALVE ASSY:DAMPED; KOBE; COMP, 1ST SUC	0	0	0
6138954	VALVE ASSY:DAMPED; KOBE; COMP, 1ST DIS	0	0	0
6138955	VALVE ASSY:DAMPED; KOBE; COMP, 2ND SUC	0	0	0
6138959	VALVE ASSY:DAMPED; KOBE; COMP, 2ND DIS	0	0	0
6138961	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1	1	1
6138956	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	0	0	0
6138958	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	0	0	0
6138962	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1	1	1
6138960	SPRING,HELICAL:VALVE; KOBE KM-2 COMPR	15	15	15
6139699	1ST CYLINDER LINER:KOBE; COMPR	0	0	0
6139710	ROD,PISTON:ASSY; 1ST-STG; KOBE; COMP	0	0	0
6139709	ROD,PISTON:ASSY; 2ND-STG; KOBE; COMP	0	0	0
6143118	PACKING ROD ASSY:2ND-STG; KOBE; COMP	0	0	0
6152255	VALVE,BLEED:KOBE KM-2 COMPR	0	0	0

Forecasting Calculations with the Croston Method

The following are the results of the calculation of forecasting the need for CO2 Compressor parts for the PIM-1 Factory for three years (2023 – 2025) using the Croston method.

Table 3. Results of Forecasting Needs with the Croston Method

No. Material	Spare Parts Specification	Period *Forecasting*		
		2023	2024	2025
		A Need for Help		
6138949	RING,PISTON:KOBE KM-2 COMPR, 2ND STG	1	1	1
6138950	RING,PISTON:KOBE KM-2 COMPR, 1ST STG	0	0	0
6138937	RING,BREAKER; 88.9X120.7X15.6MM; BRZ/SS	1	1	1
6138942	RING,BACK-UP:89.2X120.7X6.3MM; BRZ/SS	2	2	2
6138953	VALVE ASSY:DAMPED; KOBE; COMP, 1ST SUC	0	0	0
6138954	VALVE ASSY:DAMPED; KOBE; COMP, 1ST DIS	0	0	0
6138955	VALVE ASSY:DAMPED; KOBE; COMP, 2ND SUC	0	0	0
6138959	VALVE ASSY:DAMPED; KOBE; COMP, 2ND DIS	0	0	0
6138961	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1	1	1
6138956	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	1	1	1
6138958	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	1	1	1

No. Material	Spare Parts Specification	Period *Forecasting*		
		2023	2024	2025
		A Need for Help		
6138962	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1	1	1
6138960	SPRING,HELICAL:VALVE; KOBE KM-2 COMPR	18	18	18
6139699	1ST CYLINDER LINER:KOBE; COMPR	0	0	0
6139710	ROD,PISTON:ASSY; 1ST-STG; KOBE; COMP	0	0	0
6139709	ROD,PISTON:ASSY; 2ND-STG; KOBE; COMP	0	0	0
6143118	PACKING ROD ASSY:2ND-STG; KOBE; COMP	0	0	0
6152255	VALVE,BLEED:KOBE KM-2 COMPR	0	0	0

Calculation of Forecasting Errors

In this sub-chapter, the error of each forecasting method will be compared by looking at the Mean Absolute Deviation (MAD) value. The smaller the error value, the more accurate the forecasting results will be. Below are the error values for each forecasting method used.

Table 4. Forecasting Error Calculation Results

No. Material	Spare Parts Specification	Calculation of *Forecasting Errors*		
		HIS	SBA	CROSTON
6138949	RING,PISTON:KOBE KM-2 COMPR, 2ND STG	2,83	2,27	2,40
6138950	RING,PISTON:KOBE KM-2 COMPR, 1ST STG	1,18	0,81	0,84
6138937	RING,BREAKER; 88.9X120.7X15.6MM; BRZ/SS	0,85	1,00	1,05
6138942	RING,BACK-UP:89.2X120.7X6.3MM; BRZ/SS	1,52	2,59	2,76
6138953	VALVE ASSY:DAMPED; KOBE; COMP, 1ST SUC	0,46	0,31	0,32
6138954	VALVE ASSY:DAMPED; KOBE; COMP, 1ST DIS	0,46	0,31	0,32
6138955	VALVE ASSY:DAMPED; KOBE; COMP, 2ND SUC	1,16	0,78	0,80
6138959	VALVE ASSY:DAMPED; KOBE; COMP, 2ND DIS	0,93	0,62	0,64
6138961	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1,72	1,89	2,01
6138956	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	0,71	0,69	0,75
6138958	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	0,71	0,69	0,75
6138962	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1,36	1,45	1,56
6138960	SPRING,HELICAL:VALVE; KOBE KM-2 COMPR	23,13	25,50	27,02
6139699	1ST CYLINDER LINER:KOBE; COMPR	0,24	0,16	0,16
6139710	ROD,PISTON:ASSY; 1ST-STG; KOBE; COMP	0,24	0,16	0,16
6139709	ROD,PISTON:ASSY; 2ND-STG; KOBE; COMP	0,24	0,23	0,25
6143118	PACKING ROD ASSY:2ND-STG; KOBE; COMP	0,43	0,31	0,32
6152255	VALVE,BLEED:KOBE KM-2 COMPR	0,64	0,47	0,48
Forecasting Error Average		**2,15**	**2,24**	**2,37**

In table 4, the smallest error value is forecasting using the Single Exponential Smoothing (SES) method; after knowing the best forecasting method of the three forecasting methods used, the method will be used to forecast spare parts demand for the next three years. For the forecasting for the next three years, starting with calculations for 2023 to 2025 for each of these parts, you can see table 4.6.

Comparison of Inventory Costs of Needs Forecasting Results for Each Spare Parts with Existing Methods at PT Pupuk Iskandar Muda

Table 5. Estimated Costs Needed for Inventory Fulfillment in 2023 and Comparison with Existing Methods at PT PIM

No. Material	Spare Parts Specification	Calculation Results *Forecasting* 2023		Existing Methods in PIM	
		Qty	Estimated Costs Needed	Qty	Estimated Costs Needed
6138949	RING,PISTON:KOBE KM-2 COMPR, 2ND STG	1	14.605.000	1	14.605.000
6138950	RING,PISTON:KOBE KM-2 COMPR, 1ST STG	1	19.570.000	1	19.570.000
6138937	RING,BREAKER; 88.9X120.7X15.6MM; BRZ/SS	1	16.000.000	1	16.000.000
6138942	RING,BACK-UP:89.2X120.7X6.3MM; BRZ/SS	1	22.000.000	1	22.000.000
6138953	VALVE ASSY:DAMPED; KOBE; COMP, 1ST SUC	1	75.888.000	1	75.888.000
6138954	VALVE ASSY:DAMPED; KOBE; COMP, 1ST DIS	1	75.888.000	4	303.552.000
6138955	VALVE ASSY:DAMPED; KOBE; COMP, 2ND SUC	1	75.888.000	1	75.888.000
6138959	VALVE ASSY:DAMPED; KOBE; COMP, 2ND DIS	1	75.888.000	1	75.888.000
6138961	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1	1.517.000	1	1.517.000
6138956	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	1	1.517.000	7	10.619.000
6138958	VALVE PLATE:KOBE; COMP; 1ST SUC&DIS	1	1.517.000	1	1.517.000
6138962	VALVE PLATE:KOBE; COMP,1ST SUC&DIS	1	1.517.000	1	1.517.000
6138960	SPRING,HELICAL:VALVE; KOBE KM-2 COMPR	11	61.600.000	1	5.600.000
6139699	1ST CYLINDER LINER:KOBE; COMPR	1	800.000.000	1	800.000.000
6139710	ROD,PISTON:ASSY; 1ST-STG; KOBE; COMP	1	587.209.696	1	587.209.696
6139709	ROD,PISTON:ASSY; 2ND-STG; KOBE; COMP	1	587.209.696	1	587.209.696
6143118	PACKING ROD ASSY:2ND-STG; KOBE; COMP	1	249.984.000	3	749.952.000
6152255	VALVE,BLEED:KOBE KM-2 COMPR	1	13.392.000	6	80.352.000
	Total Estimated Cost Required		**2.681.190.392**		**3.428.884.392**

Remarks: According to the results of the spare parts classification that the 18 items above are in the high category (inventory of goods needed), then it is assumed that the quantity of inventory = 1 for each result of forecasting needs = 0.

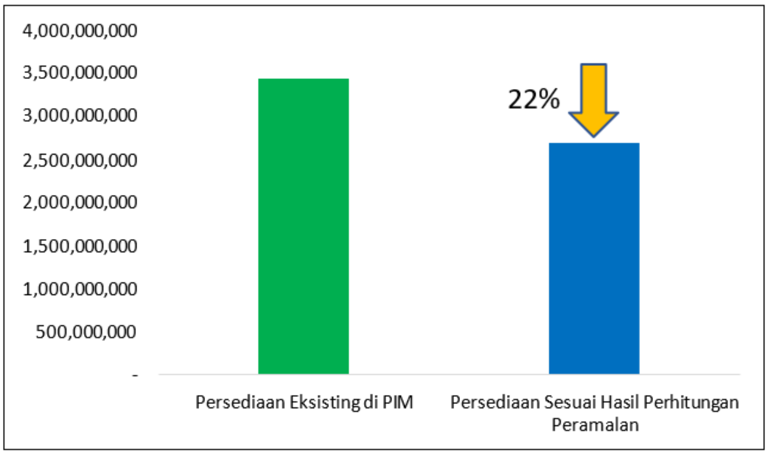

Figure 3. Estimated Cost Efficiency of Spare Parts Inventory

From the calculation of the cost estimate above, the cost of inventory needed for the existing method is greater than the cost of the calculation results of forecasting using the Single Exponential Smoothing (SES) method. By using the results of forecasting needs using the SES method, an inventory cost efficiency of 22% was obtained.

CONCLUSION

Based on the data processing and analysis, it was found that out of 20 spare parts items used in the *CO_2 Compressor* of the *PIM-1 Factory*, 18 items were classified as high priority (requiring inventory), while 2 items—*PIN, CROSSHEAD, STEEL, 203X425, 5MM* and *STUD BOLT: 1-1/2INX UNX445MM; STEEL*—were categorized as low priority (non-stock). Forecasting for the 18 high-priority items using *Single Exponential Smoothing* (*SES*), *Syntetos-Boylan Approximation* (*SBA*), and *Croston* methods showed that SES produced the lowest forecasting error, with an average *Mean Absolute Deviation* (*MAD*) of 2.15, compared to 2.24 for SBA and 2.37 for Croston. Implementing the SES-based forecasting approach resulted in a 22% reduction in inventory costs, lowering the estimated 2023 inventory cost from IDR 3.428 billion to IDR 2.681 billion. For future research, it is recommended to expand the sample size and explore the integration of advanced forecasting techniques, such as machine learning models, to further improve the accuracy and efficiency of spare parts inventory management.

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