

CHAPTER 4 – RESULT AND DISCUSSION

4.1 Define

High inventory cost spare parts of the Air Compressor has impact to financial cost overall, the process made to determine spare parts need to be stocked and their quantities, tend to be highly subjective, depending on the experiences and knowledge of the person in charge at that time.

4.1.1 Cause and Effect Analysis (Ishikawa Diagram)

Cause and effect analysis is use to understand the fundamental reasons behind the research problem or the factors that contribute to the phenomenon and pinpoint the potential root causes or key contributing factors to the research problem.

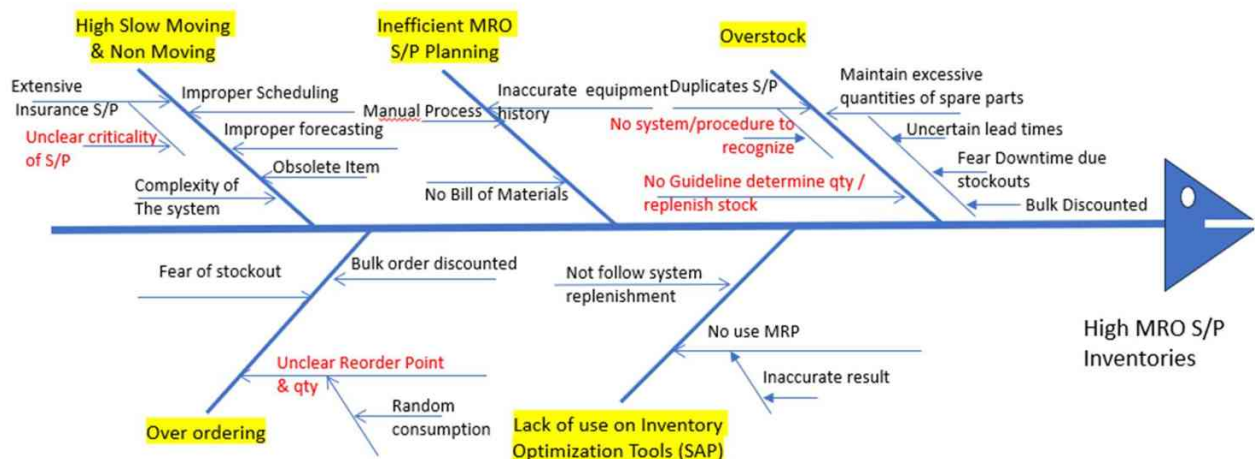


Figure 8. Root Cause Analysis by Why-Why Method

Figure 8 shows the investigation of the problem's root cause, it is categorized into five sections, which include High Slow Moving and Non-Moving (Dead Stock). Inefficient Maintenance Repair and Overhaul (MRO) spare parts (S/P) planning, overstock, over ordering, and lack of use on optimization tools (SAP). High Slow moving and Non-Moving spare parts was happened due to during deciding which parts should be stock was unclear, which one is important/critical and which one is not important/critical, the person in charge who decide to stock are rely on his own knowledge and experiences.

The inefficiency in MRO Spare Parts (S/P) Planning occurred due to an imbalance between the prepared spare parts planning and the actual execution. This imbalance was influenced by schedule changes and the historical consumption patterns of parts. Overstock arises when an organization holds more inventory than it can effectively utilize within a reasonable timeframe. In some instances, overstock is attributed to the presence of identical model/type spare parts with different codes, lacking a recognition system. Furthermore, there is a lack of guidelines for the person in charge on how to determine the replenishment quantity.

Overordering takes place when an organization acquires more inventory than is genuinely needed for its current or anticipated demand. This issue is exacerbated by the absence of a clear formula for the reorder point, contributing to the challenge of aligning inventory levels with actual requirements.

4.1.1 Solution

The Ishikawa diagram helps identify the root cause, and a decision on an alternative solution can be reached through a focus group discussion utilizing the 5W1H tools.

Table 3. 5W1H tools

Category (What)	Root (Why)	Cause	Solution (How)	Who	When	Where
<i>High Slow and Non-Moving Overstock</i>	Unclear Criticality of Spare Parts		Develop decision procedure	Reliability Engineer	November 2023	Cilegon
	No system/ Procedure to recognize duplicates		Develop Procedure to recognize over duplicate	Reliability Warehouse Officer	November 2023	Cilegon
<i>Overstock</i>	No Guideline replenish qty		Develop reorder procedure	Reliability Engineer	November 2023	Cilegon
<i>Over Ordering</i>	Unclear reorder point/ qty			Warehouse Officer	November 2023	Cilegon

Table 3 explain the issue of high slow and non-moving inventory was attributed to the lack of clarity regarding the criticality of spare parts. In response, a decision matrix procedure is set to be developed, ensuring a systematic approach to assess and categorize the

importance of each spare part. The responsibility for implementing this solution lies with the Reliability Engineer, with a targeted completion date in November 2023.

Overstock situations were identified as stemming from the absence of a system or procedure to recognize duplicate items in the inventory. A solution has been proposed in the form of a developed procedure to identify and address duplicates. The Reliability Warehouse Officer is entrusted with the responsibility of implementing this procedure, with the targeted completion date set for November 2023.

Overordering were also identified as resulting from the absence of guidelines for replenishment quantity and also an unclear reorder point and quantity. A solution has been proposed to develop a reorder procedure based on the Economic Order Quantity (EOQ) model. Both the Reliability Engineer and Warehouse Officer are collaboratively responsible for implementing this procedure, with a targeted completion date in November 2023.

To develop stocking policy for MRO spare parts inventory management, it involves collaboration between maintenance and logistics perspectives, balances the need to minimize downtime with cost optimization, also need considers both operational and cost factors. The aims is to align the stock policy with overall maintenance and operational objectives.

The critical spare parts analysis will follow such process as shown in Figure 9.

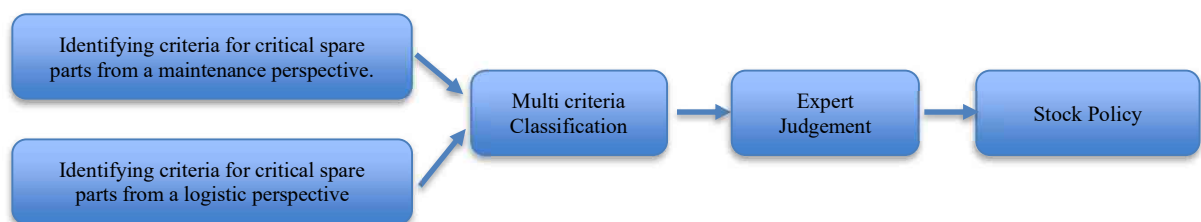


Figure 9. Process of defining stock policy

4.2 Measure

During the measurement phase, tasks will encompass gathering data and conducting measurements. The literature studied spans from 2008 to 2020, followed by a gap analysis

of each relevant literature. Subsequently, data on MRO spare parts inventory is extracted from the maintenance warehouse, covering the period from the beginning of the fiscal year 2016 to the end of the fiscal year 2022. The collected data is then processed to derive measurements, including non-moving and slow-moving parts, lead time, and parts values.

4.2.1. Data Collection of Current MRO Spare Parts Stock Analysis

Currently, the spare parts are analysed using FSN classification which is based on a single parameter (consumption), which takes into account the frequency at which the parts are moved. At present the amount value of inventory, 39% of the items in stock are classified as non-moving, 42% are classifying as slow moving and 20% as Fast Moving. This classification highlights the spare parts that have not been fully utilized for previous 13 years from 2009 until 2022 are 39% until 81%.

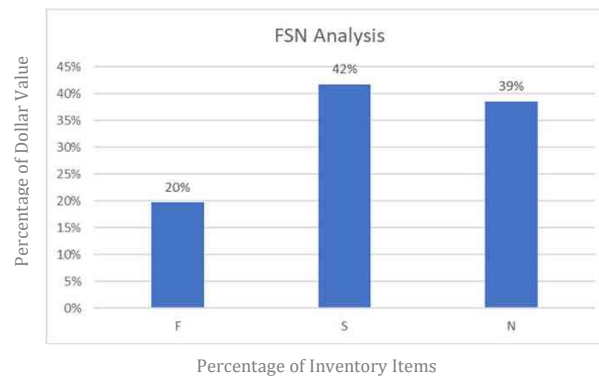


Figure 10. Current Inventory overview by FSN Analysis

ABC analysis also used to analyse based on their importance, representing a different level of significance.

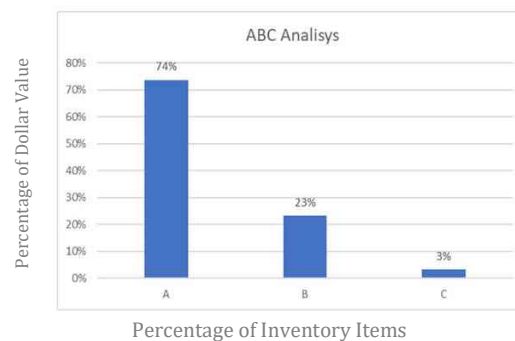


Figure 11. Current Inventory overview by ABC Analysis

Figure 12 exhibits the existing amount of inventory based on ABC analysis, at present the amount value of inventory, 74% of the items in stock are classified as A category, 23% are classifying as B category and 3% as C category. This classification highlights the spare

parts which is have long delivery times, expensive, and have low demand is significant amount on A Class.

4.2.2 Research Gap Study

Maintenance and spare parts inventory management are intricately linked and should be considered in tandem. Striking the optimal balance between the costs associated with spare parts, inventory, stock, and the expenses incurred by not using spare parts is crucial. The primary focus should be on minimizing downtime costs

Here are the findings from the literature review, highlighting the research gap and existing studies on identifying commonly used methods for determining critical spare parts and also the criteria for classification must encompass maintenance and logistical perspectives, as both functions play a crucial role in determining decisions related to spare parts stock levels.

Table 4. Spare Parts Criticality Approach method and Evaluation Criteria

Author		Orlando Durán (2015)	Maria ulfa (2020)	Sudamaji (2022)	Gao Jingjiang (2012)	Oliveira (2017)	Mehmet (2019)	Tsakatikas (2008)	Endrianto (2020)
Approach Method	AHP	X			X		X		
	Fuzzy Logic						X		
	Taguchi						X		
	FMEA			X					
	FMECA		X					X	
	ABC			X	X	X			
	VED					X			X
Evaluation Criteria	Logistic	Price/Cost	X	X		X	X		X
		Lead time		X	X		X		X
		Demand/ Usage		X	X	X	X		X
		Population/ Substitution			X				X
		Failure Probability	X	X					X
		Supplier Number	X				X		
	Maintenance	Repair time					X		X
		Stock Out Impact	X	X		X			
		Quantity in Stock			X				
		Failure Mode and Potential Risk Severity		X	X			X	
		Maintenance Policy	X					X	
		Asset Criticality	X						
		Residual Risk				X			
		Employee Qualification							X

The approaches listed at Table 3 are various methods used to determine the criticality of spare parts in maintenance management. Each method employs different techniques and models to assess the importance of spare parts in a systematic manner. AHP is a decision-making technique that helps prioritize alternatives in a complex decision hierarchy.

It includes decomposing a decision into a hierarchical structure and employing pairwise comparisons to ascertain the relative significance of criteria. AHP can be applied to assess the criticality of spare parts by considering factors such price, failure probability, supplier number, stock out impact, maintenance policy and asset criticality (Durán, 2015).

FMEA is a systematic method for evaluating processes or products to identify potential failure modes, assess their consequences, and prioritize them based on severity, occurrence, and detection. It can be utilized to evaluate the criticality of spare parts through an analysis of potential failure modes and their influence on the overall performance of the system. Combine with ABC Analysis approach method to assess criticality of spare parts by considering several factors such as price, demand, and quantity in stock.

FMECA extends FMEA by including criticality analysis, which adds an additional dimension to assess the importance or criticality of each potential failure mode. It's providing a more comprehensive analysis by considering both failure modes and their criticality, aiding in prioritizing spare parts based on their impact on system performance. FMECA can be applied to assess the criticality of spare parts by considering factors such price, lead time, demand, failure probability, and stock out impact.

The ABC analysis classifies items into three categories (A, B, and C) depending on their level of significance. Class A items are the most critical, while Class C items are less critical. Its analysis is a simple and widely used method to categorize spare parts based on their criticality, helping organizations prioritize their management efforts. ABC can be utilized to evaluate the importance of spare parts by taking into account factors such as price, lead time, and demand. VED analysis classifies spare parts into categories based on their criticality to the system. It considers factors such as Vital, Essential, and Desirable. It's helps prioritize spare parts based on their importance to system functionality, emphasizing the critical ones that are vital or essential

It can be used to evaluate the importance of spare parts by taking into account factors such as price, lead time, demand, population, failure probability, repair time, and employee qualification.

Spare parts play a critical role in the efficiency, reliability, and productivity of the petrochemical industry. The industry's reliance on these components makes their proper management essential to ensure uninterrupted operations. Unsuitable inventory policies can lead to prolonged machinery downtime, emphasizing the need for careful consideration in spare parts evaluation and control throughout different phases of the asset's life cycle. (Innuphat et.al, 2022) (Jiazhong, Lu, 2022). The petrochemical industry faces challenges in determining initial spare parts inventories due to limited historical data, and the high uncertainty in the demand for spare parts makes control a tedious process. Criticality, classification, and data management are identified as crucial aspects of spare parts, necessitating optimization and continuous improvement in spare parts management practices. (Kusumawardhani, 2020) (Irene et.al, 2014)

The characteristics of spare parts in the petrochemical industry include their hazardous nature, capital-intensive status, and the challenge of minimizing downtime and costs. The industry also grapples with issues such as erratic and intermittent demand, complexity in inventory management, lumpy demand, and a larger variety of spare parts, which pose risks of stock obsolescence. (Lidiane, 2016) (Eman, 2012)

Based on research gap on some literature and also observation result in petrochemical industry, concluded that effective spare parts management in the petrochemical industry requires a comprehensive approach that considers criticality, classification, data management, and optimization strategies. It involves addressing challenges related to demand uncertainty, inventory complexity, and the unique characteristics of spare parts in a hazardous and capital-intensive environment. Among the listed approaches and evaluation criteria, the most suitable method for determining spare parts criticality in the petrochemical industry is the FMEA (Failure Modes, Effects Analysis) approach. This method involves a systematic evaluation of potential failure modes, their effects on the system with a focus on reliability and safety, making it well-suited for the petrochemical sector. The result of Risk Priority Number on FMEA will be convert into the criteria of

spare parts importance such as VED (Vital, Essential and Desirable) to obtain the best alternative choices of several potential candidates in decision.

Several evaluation criteria in logistic perspective and also maintenance perspective allows organizations to strike a balance between cost-effectiveness, operational efficiency, and risk mitigation. In term of logistic, evaluating criteria such as Price/Cost is a crucial factor in logistic decision-making. It directly impacts the financial aspects of inventory management and procurement. Understanding the price/cost allows organizations to make cost-effective decisions and optimize their budget.

Long lead times can result in extended machinery downtime, negatively affecting operations. Shorter lead times are preferred to ensure a quick response to equipment failures and maintenance needs. Analysing the demand and usage patterns of spare parts helps in determining optimal stock levels. It ensures that there are enough spare parts on hand to meet the expected demand, reducing the risk of stockouts and operational disruptions.

Assessing the population of a spare part and the availability of substitutes is important for managing variations in demand and supply. It helps organizations plan for potential changes in the availability of specific spare parts and consider alternative options.

Understanding the likelihood of failure for a spare part is critical for proactive maintenance planning. It allows organizations to prioritize maintenance efforts on components with a higher risk of failure, enhancing overall system reliability. Evaluating the number and reliability of suppliers ensures a diversified and dependable supply chain. Dependence on a single supplier can pose risks, such as disruptions due to supplier issues. Multiple suppliers provide alternatives and reduce the impact of potential supplier-related challenges

In terms of maintenance perspective, the time required to repair a component directly influences how quickly a system can be restored to operational status. Minimizing repair time is essential for reducing downtime and maintaining optimal productivity. Assessing

the impact of stockouts helps in understanding the consequences of not having a spare part when needed. This perspective allows organizations to prioritize critical spare parts and implement strategies to mitigate the effects of stockouts. Knowing the quantity of spare parts in stock is fundamental for inventory management. It helps in maintaining an appropriate level of inventory to meet demand while avoiding excess stock that ties up capital.

Understanding the existing maintenance policy provides insights into the overall approach to maintenance activities. It helps in aligning spare parts management strategies with the organization's broader maintenance objective. Assessing the criticality of assets impacted by spare parts ensures that resources are allocated to components that have the most significant impact on overall system performance. Critical assets may require more attention and resources in terms of spare parts management and maintenance.

The table below contains studies conducted to determine the methods applied in establishing the quantity of spare parts to be stocked or replenishment model and its relationship with the applied maintenance strategy.

Table 5. Replenishment Policy

Author		Prem Vrat (2014)	Yuka Sato (2019)	Feviana Betsi (2018)	Adhi et.al (2015)	Norhafiza et.al (2018)	Endah (2017)	Geurts (1992)	Ialuh et.al (2020)	Moharana (2016)	Noor-Ajlan et.al (2013)	Shibuya (1998)	Robert (2022)
Replenishment Policies	Continues Review						X					X	
	Periodical Review			X	X	X			X	X			
	Economic Order Quantity – Re-order Point/ Quantity		X								X		
	Single Purchase Model	X						X					X
	Return on Investment Model												X
Maintenance Strategy	Periodical Inspection (Condition Based Maintenance)										X		
	Periodical Maintenance (Time Based Maintenance)		X		X	X				X	X		
	Breakdown Maintenance (Corrective Maintenance)	X					X	X	X			X	
Categorized Spare Parts Policy	Insurance	X					X	X	X			X	X
	Operation		X	X	X	X							
	Consumable									X	X		

The common term used to distinguish the types of spare parts stocked policy is insurance, operation, and consumable, each of which has different characteristics and purposes. Insurance spare parts are critical components kept in stock to minimize downtime in the event of unexpected failures or emergencies, these parts serve as a form of insurance against unplanned disruptions by ensuring that essential components are readily available, reducing the risk of prolonged equipment downtime.

Operation spare parts are components that are regularly used during the normal functioning of a machine or system, these parts are essential for the routine operation and maintenance of equipment. They are typically replaced as part of preventive maintenance to sustain the optimal performance of the machinery.

Consumable spare parts are items that have a limited lifespan and are expected to wear out or deplete over time with regular use, these parts are regularly consumed or replaced during the normal course of operations. Examples include filters, lubricants, and other components that require periodic replacement to maintain the efficiency and reliability of the equipment.

Based on study on stocking method, each spare parts which is categorized as insurance, operation and consumable will be formulize as Eq (4.1) and Eq (4.2);

For Insurance Spare Parts, stocking model will be used Return on Investment principle an economic analysis to justify whether the stock is necessary or not. There will be variable S = Spare Unit Cost (US Dollar), Fb =Life Time estimation (days), Dt = Delivery time (days), El = Economic Loss per day (US Dollar).

$$\text{Downtime Value (Dv)} = (El \times Dt) / Fb \quad (\text{US Dollar}) \quad \text{Eq. (4.1)}$$

$$\text{Payout (Po) will be } Po = S / Dv \quad (\text{Years}) \quad \text{Eq. (4.2)}$$

If the Po less than equal 3 years, then it is visible to have stock spare parts.

For Operation Spare Parts, stocking model will be used service level or target availability, which can be thought of as the expected probability of not hitting a stock-out. which is a function of the spare's criticality, and of its unit price. Spares unit price impacts also on the required service level. We use a qualitative approach to categorize the spares into three groups (High, medium low) according to their unit price, the price thresholds for these groups are set as below

Table 6. Spare Parts Price Threshold

Price level	Price Threshold
Low	Less than equal USD1000
Medium	Greater than USD1000 and Less than equal USD5000
High	Greater than USD5000

The service level matrix offered here shows how the spare's criticality combines with its unit price to determine the required service level. We see that, when the spares criticality is high and the spares price is low, then the service level is high; which means that low-cost but important spares should have a high availability.

Table 7. Service Level

Service Level (High 98%, Medium 95%, Low 90%)			
Unit Price	Spare Criticality		
	High	Medium	Low
Low	High	High	Medium
Medium	Medium	Medium	Low
High	Medium	Low	Low

Conversely, when the spares criticality is low and the spares price is high, then the required service level is low, i.e., we should have a lower availability. This company quantify the service levels according to the inventory budget. The service levels are defined as 98%, 95% and 90% for the high, medium and low categories, respectively. There will variable that will be related to the stocking number for operational spare, such as S_c = Spare Criticality, S = Spare Unit Price F = Failure Probability

$Demand = Failure\ Probability \times Item\ Parts\ qty$

For consumable spare parts, have characteristics opposite to those of insurance spares, Based on the characteristics of consumable spares, we can model consumption using EOQ model. The EOQ principle is to balance the holding cost with ordering cost. There are four main parameters in EOQ model there are demand rate, lead time, ordering cost and holding cost. The EOQ formula as mention in chapter 2

Common characteristics can be essential for developing standardized practices, management strategies, or decision-making processes that apply broadly to various types of spare parts, it can be categorized as shown at Table 8:

Table 8. Spare Parts Characteristic

Parameters	Consumable	Operational	Insurance
Price	Low	Medium	High
Lead Time	Short	Medium	Long
Quantity in use	Large	Medium	Few
Service Life	Short	Medium	Long

4.3 Analyse

From the results of literature studies, it is known that there are 14 criteria influencing the criticality level of a spare part. Among them, from the logistic perspective, these include price/cost, lead time, demand/usage, population/substitution, failure probability, and the number of suppliers. From the maintenance perspective, they include repair time, stock out impact, quantity in stock, failure mode, maintenance policy, asset criticality, residual risk, and employee qualification. From these criteria, we will determine the relevant ones using the cut-off point method, as demonstrated, for instance, by Tummala in 2001. The utilization of this approach aids in identifying pertinent criteria, thus mitigating the challenge of dealing with numerous criteria. In this technique, senior engineers across diverse disciplines assign weights to each criterion as follows: 1 if the criterion is deemed unimportant, 2 if it is somewhat important, and 3 if it is considered very important. Subsequently, the average weight for each criterion is calculated based on the experts' assigned weights, as illustrated in Figure 13. The cut-off value of 2.4 is determined by taking into account the highest average (2.9, refer to Figure 13) and the lowest average (1.9, refer to Figure 13) among the criterion values. Employing this threshold value enables the selection of the most relevant criteria, as depicted in Table 9, along with the definition of criticality criteria. Importantly, this proposal remains adaptable for application with various criteria.

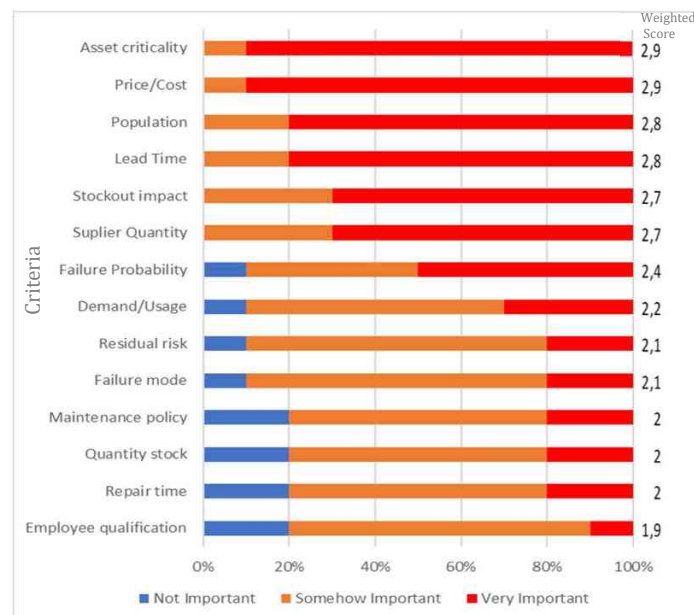


Figure 12. Selection of Criteria

By using the cut-off method, we can select the most relevant criteria, as seen in Table 9, along with their definitions. Because the relationship between stockout impact and lead time is closely intertwined, the author concludes that stockout impact is strongly associated with the length of lead time required to provide the necessary spare parts for maintenance or repair activities. Therefore, in Table 9, the stockout criterion is excluded.

Table 9. Criticality Criteria

Criticality Criteria	Description
Maintenance	
Asset Criticality	The importance or significance of an asset within an organization or system, it involves assessing and determining the level of impact that the failure or degradation of a particular asset would have on the overall performance, safety, reliability, and quality.
Population	Number of similar or identical equipment units within a specific category or group.
Failure Probability	A statistical measure that quantifies the likelihood of a system, component, device, or process experiencing a failure within a specified period.
Logistic	
Price	Purchase spare parts value include commercial process
Lead Time	The duration required for a process to complete, starting from the initiation of a request and until the final delivery.
Supplier Numbers	The quantity of suppliers for specific parts or components,

The classification of the chosen criteria was done using the VED method. Table 10 presents an overview of the three classifications: Vital, Essential, and Desirable. These classifications were determined based on the company's system and insights gathered from interviews with experts in the reliability maintenance department.

Table 10. Criteria Classification use VED

	Categories		
Criticality Criteria	Vital	Essential	Desirable
<i>Maintenance</i>			
Asset Criticality	Asset Failure has immediate impact on production and serious consequences on safety and environment	Asset Failure will increase the risk of production loss or increase the risk to safety and environment	Asset failure has limited consequences on production or increase risk to safety and environment
Population	Single asset	Redundant Asset	Similar Asset more than 2
Failure Probability	Unpredictable failure	Predictable Failure	No Need for predictable failure
<i>Logistic</i>			
Price	Greater than equal USD 5000	Greater than USD 1000 and Less than USD 5000	Below USD 1000
Lead Time	Greater than equal 4 months	Greater than equal 2 weeks and less than 4 months.	Less than 2 weeks
Supplier Number	Single Supplier	2 suppliers	More than 2 suppliers

AHP was used to assist in the multi-criteria decision-making process for spare parts inventory management in the petrochemical company. It helps in determining the relative weights of different criteria and alternatives, allowing decision-makers to prioritize and make informed decisions. In the Analytic Hierarchy Process (AHP), the verbal statements are transformed into a numerical scale ranging from 1 to 9. This scale represents the extent to which one element is more important than another in relation to the analysed criteria. Experts assess the criteria at each corresponding level, resulting in numerous comparisons

at each level. The number of pairwise comparisons (I) can be determined by a function that takes into account the number of elements (n), which is given by $I = \frac{n(n-1)}{2}$ (Saaty, 2008). In order to ensure consistency in the AHP method, the judgments are examined using eigenvalues and eigenvectors of the comparison matrices. A consistency ratio (CR) of 10% or less is considered acceptable (Saaty, 1990). Based on the criteria in Table 10, the following are the results of the AHP for the Maintenance perspective:

Table 11. AHP for Maintenance Perspectives

CRITERIA	ASSET CRITICALITY	POPULATION	FAILURE PROBABILITY	WEIGHT
ASSET CRITICALITY	1	5	7	0.723506
POPULATION	1/5	1	3	0.193186
FAILURE PROBABILITY	1/7	1/3	1	0.083307

The consistency ratio from the AHP at Table 11, is 0.096089. The consistency ratios' values indicate that the judgments are consistent due to the fact that the ratio is less than 0.1. From the logistic perspective:

Table 12. AHP for Logistics Perspectives

CRITERIA	PRICE	LEAD TIME	SUPPLIER NUMBER	WEIGHT
PRICE	1	5	7	0.643388
LEAD TIME	1/5	1	3	0.282839
SUPPLIER NUMBER	1/7	1/3	1	0.073772

The consistency ratio from the above AHP at Table 12 is 0.083384. The consistency ratios' values indicate that the judgments are consistent due to the fact that the ratio is below 0.1. The diagram at Figure 13 is a hierarchy process diagram in determining the total criticality

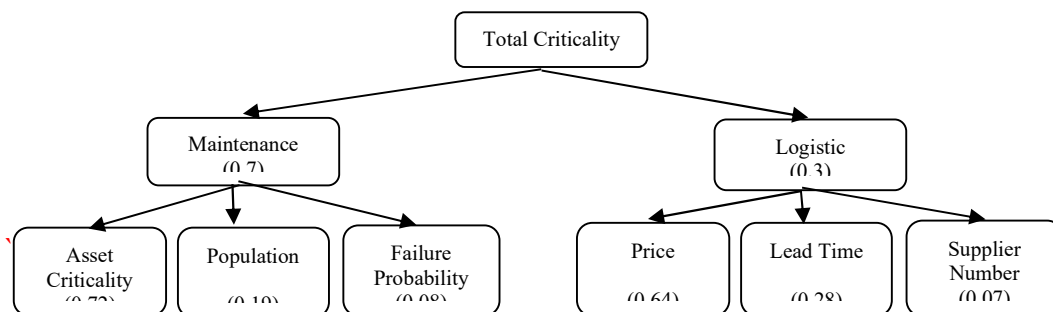


Figure 13. Total Criticality use AHP

Based on table 10 and table 11, it is clear that the most important factor is criticality of the asset for determining inventory stock based on the importance of a spare part. This refers to how much the spare part is needed to ensure production availability, safety, and environmental integrity. Hereafter, the price of the spare part is seen as a key factor in deciding whether it should be stored. For petrochemical companies, lead time is also a significant consideration, especially when a large portion of their spare parts are imported.

4.3.1 Multi Criteria Decision Model-A

Model A is utilized as a decision model for achieving a optimal solution which combines selected spare parts criteria and previously established spare parts criticality. This integrated approach is employed to assess and prioritize the required spare parts as well as determine the appropriate stocking levels. Model-A specifically characterizes spare parts with a high level of criticality, particularly those installed in assets with high asset criticality.

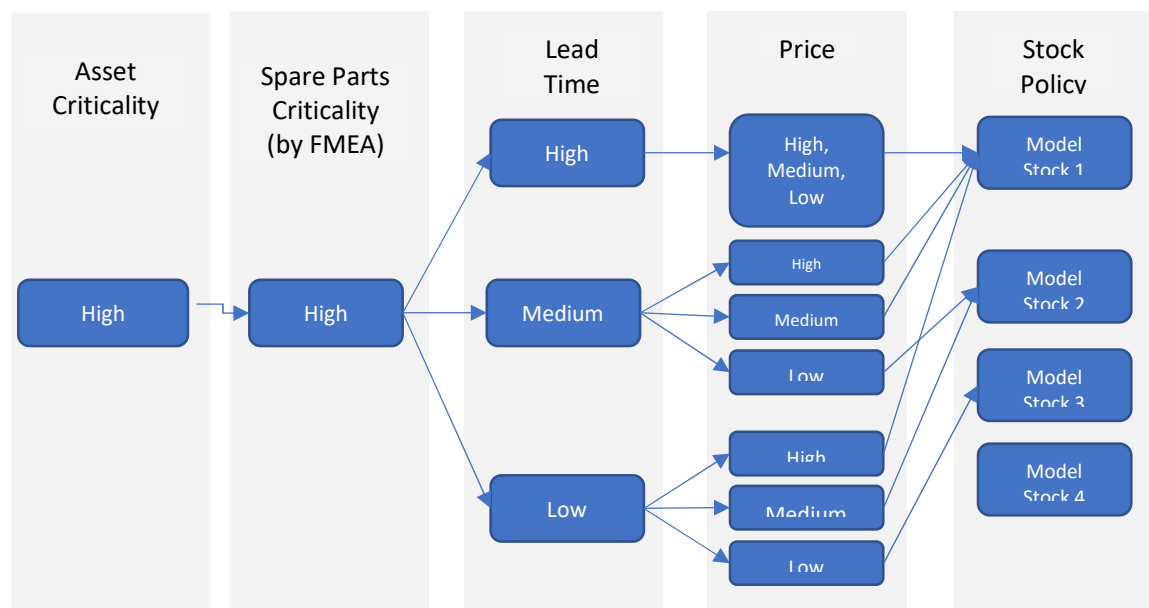


Figure 14. Decision Model-A

4.3.2 Multi Criteria Decision Model-B

Model-B specifically characterizes spare parts with a medium level of criticality, particularly those installed in assets with high asset criticality.

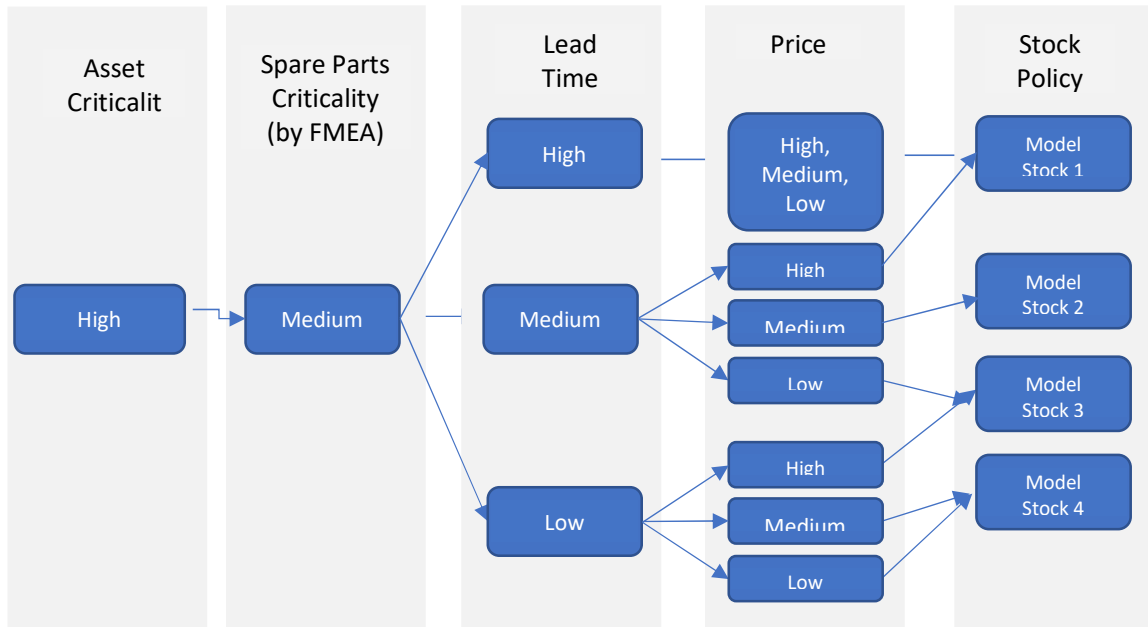


Figure 15. Decision Model-B

4.3.3 Multi Criteria Decision Model-C

Model-C specifically characterizes spare parts with a Low level of criticality, particularly those installed in assets with high asset criticality.

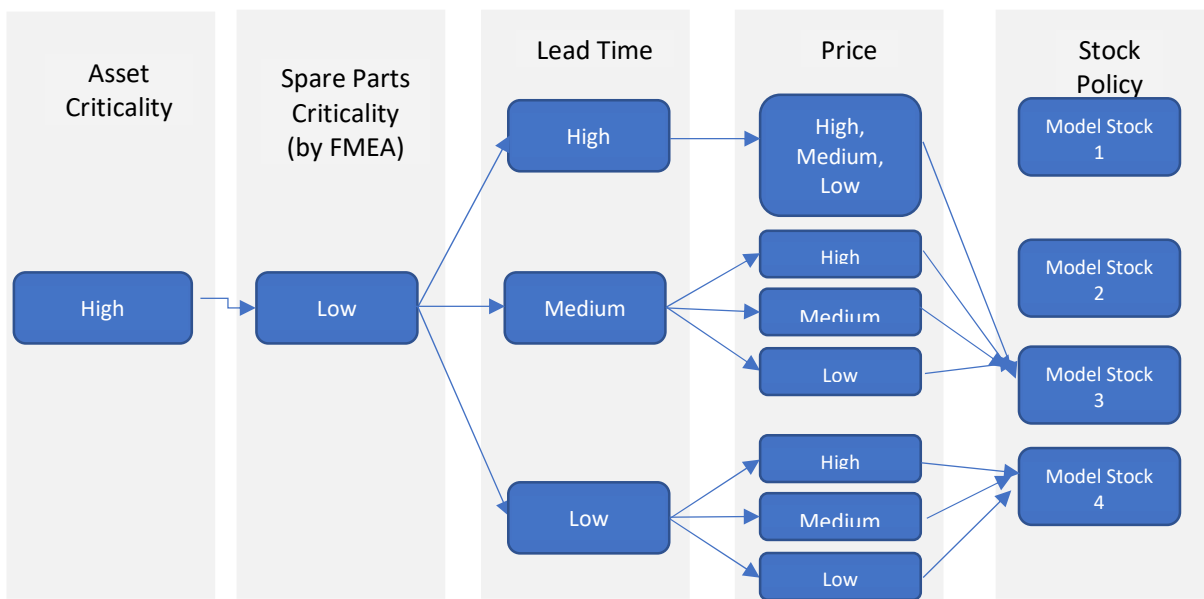


Figure 16. Decision Model-C

4.3.4 Model Stock Policy

These models as shown in Table 13 provide different perspectives on managing inventory and making purchasing decisions, addressing various aspects such as return on investment, emergency preparedness, periodic reviews, and flexibility in procurement strategies.

Table 13. Model Stock Policy

Model Stock Policy	Formula
Model Stock-1	If ROI less than 3 Years = Need to Stock $ROI = (\text{Unit Spare Price} + \text{Repair Cost}) / \text{Loss Cost due downtime.}$ $MIN = \text{Safety Stock (SS) for Emergency Case} = \text{Similar Parts Qty} * \text{Population Factors}$
Model Stock-2	$MIN = (\text{Safety Stock (SS) for Emergency Case} + \text{Stock Condition Based}) * \text{Similar Part Population Factor} + (\text{Monthly Consumption} * LT)$
Model Stock-3	<u>Periodical Review</u> $MIN = ROP$ $MAX = ROP + EOQ$ $ROP = (SS + (\text{Monthly Consumption} * LT))$ $EOQ = \underline{\hspace{2cm}}$
Model Stock-4	No Stock, Consignment, Buy on demand.

Model Stock-1 is characterized for a high value spare parts with a long Lead time, typically spare subcomponent for a machine whose penalty cost downtime is extremely high then it uses a ROI-driven perspective, the decision to stock or not to stock spare parts based on the Return on Investment (ROI) is less than 3 years. This suggests a focus on optimizing inventory to minimize downtime costs. Model Stock-2 is characterized for a medium to high value spare parts with a medium lead time, the decision involves maintaining a balance between readiness for emergencies and optimizing stock based on condition and lead time. Model Stock-3 is characterized for a low to medium value spare parts with a medium lead time and has large population, the decision involves periodically reviews and adjusts reorder points (ROP) and order quantities (EOQ). Decisions are based on maintaining a balance between avoiding stockouts (ROP) and optimizing economic order quantities (EOQ). Model Stock-4 is characterized for a low value spare parts with a short lead time and has large population, the decision Offers flexibility with options like having no stock, using consignment, or buying on demand.

4.4 Improvement

4.4.1 Implementing FMEA as Spare Part Criticality Assessment

The first improvement is to develop the FMEA form used as an assessment sheet for the criticality level of spare parts. In table 18, the structure of the form is seen, consisting of several elements such as the main unit, sub-unit, core team conducting the assessment, the person responsible for FMEA activities, recording personnel, FMEA number, and creation date. For the body of the form itself, it includes asset criticality type, material code, the responsible section for maintaining the item, part category, an explanation of the part, followed by the functional analysis of the part in that sub-unit, then the potential failure analysis of the function, and potential subsequent effects.

The current control column is filled by specifying the control activities that have been carried out. Then, the assessment results from the team related to severity, occurrence, and detection follow the FMEA standard scale from 1-10.

RPN stands for Risk Priority Number. It is a numerical assessment used in risk management and particularly in Failure Mode and Effects Analysis (FMEA). RPN is calculated by multiplying three factors, *severity* (S), this factor assesses the potential impact or seriousness of the failure mode if it occurs, *occurrence* (O), this factor evaluates the likelihood or frequency of the failure mode occurring, *detection* (D), this factor reflects the likelihood of the failure mode being detected before it causes harm. The formula for calculating RPN is $RPN = Severity \times Occurrence \times Detection$, each factor is typically rated on a scale from 1 to 10, with 10 representing the highest severity, occurrence, or likelihood of detection.

Once the severity, occurrence, and detection ratings are multiplied together, the resulting RPN value provides a numerical indication of the relative risk associated with a particular failure mode. This value helps prioritize which failure modes should be addressed first in risk mitigation efforts.

Followed by calculating the RPN value it converts into High, Medium, and Low criticality levels. Severity Level is a qualitative measure used to assess the potential impact or seriousness of a failure mode on a system, process, or product as shown in Table 14.

Table 14. Severity Level

Severity	Description
Minor (1-3)	• Negligible impact on system performance or safety. • Minor adjustments or corrections can be made with minimal effort. • Little or no impact on overall operation.
Major (4-6):	• Significant impact on system performance or safety, but not catastrophic. • Requires corrective action and moderate effort to address. • Noticeable impact on overall operation.
Critical (7-10)	• Severe impact on system performance or safety, potentially leading to system failure. • Requires immediate corrective action and significant effort. • Unacceptable risk level, posing a threat to safety or critical operations
Catastrophic (10)	• Imminent system failure with severe safety implications. • Requires emergency action and immediate shutdown. • Unacceptable risk, posing a severe threat to safety or irreversible damage

Occurrence Level is a qualitative measure used to assess the likelihood or probability that a particular failure mode will occur in a system, process, or product as shown in Table 15.

Table 15. Occurrence Level

Occurrence	Description
Remote (1-3)	• Extremely rare event, unlikely to occur during the system's lifespan. • Historical data indicates rare instances of occurrence.
Unlikely (4-6)	• Infrequent event with a low likelihood of occurrence. • Historical data shows occasional incidents
Possible (7-10)	• Likely to occur occasionally during the system's lifespan. • Historical data indicates a moderate frequency of occurrences.
Likely (10)	• Frequent occurrence, expected to happen regularly. • Historical data shows frequent incidents.

Detection Level is a qualitative measure used to assess the likelihood or probability of detecting a particular failure mode before it reaches the end-user or has a significant impact on the system, process, or product.

Table 16. Detection Level

Occurrence	Description
Almost Certain (1-3):	- Extremely high probability of detecting the failure mode. - Highly visible and easily detectable during routine inspections
Remote (4-6):	- Moderate probability of detecting the failure mode. - Detectable through regular inspections and monitoring
Occasional (7-10):	- Low probability of detecting the failure mode. - Detection may require specialized testing or infrequent inspections.
Likely (10)	- Very low probability of detecting the failure mode. - Detection may be challenging and may occur only during specific conditions or events.

The range used to convert RPN values into spare parts criticality is depicted in Table 17. RPN values below 175 are classified as low, while those ranging between 175 and 250 are categorized as medium. RPN values exceeding 250 are classified as high. These categories are determined based on the management's action priority considerations, which emphasize severity of plant stop risk followed by occurrence and then detection (AIAG & VDA, 2019)..

Table 17. Criticality by RPN

RPN	Criticality Category
Less than 175	Low
Greater than equal 175 and less than equal 250	Medium
Greater than 250	High

Table 18. Developed FMEA Form for Assessment

FAILURE MODE AND EFFECTS ANALYSIS														
Main Unit : Air Compressor				Responsibility: Mr.A				FMEA number: 1						
Sub Unit : Air Compressor Stage 1-5				Prepared by: Mr.B				Page : 1 of 1						
Core Team Mr. B, Mr. C, Mr. D								FMEA Date 17/11/2023 Rev: 0						
Asset Criticality	Material Code	Section	Parts Category	Parts Description	Parts Function	Potential Failure Mode	Potential Effect(s) of Failure	Current Control	Assessment Results					
									S	O	D	RPN	S/P Criticality	
A	12000050	MECHANICAL	Bearing	RADIAL TILTING PAD BEARING, OD 220 MAT'L: Z456-9-001450/011, P/N: 51GR. 531 2-05, DWG: 454-0-004063FOR LP SHAFT ON I MPELLERSERKO-1, MAKER: MAN	Support radial loads Allow for dynamic movement and misalignments Provide stability during operation	- Fracture or fatigue of tilting pads - Misalignment leading to uneven wear - wear and tear on the bearing surface - Insufficient lubrication causing friction and overheating	High Vibration, High Temperature Catastrophic	Interlock Control, Routine Inspection	9	5	5	225	MEDIUM	
A	120000401	MECHANICAL	Bearing	RADIAL TILTING PAD BEARING, OD 220 MAT'L: Z456-9-001450/010, P/N: 50GR. 531 2-04, DWG: 454-0-004063FOR LP SHAFT ON M OTOR SIDESERKO-1, MAKER: MAN	Support radial loads Allow for dynamic movement and misalignments Provide stability during operation	- Fracture or fatigue of tilting pads - Misalignment leading to uneven wear - wear and tear on the bearing surface - Insufficient lubrication causing friction and overheating	High Vibration, High Temperature Catastrophic	Interlock Control, Routine Inspection	9	5	5	225	MEDIUM	
A	120000301	MECHANICAL	Bearing	RADIAL TILTING PAD BEARING, OD 177 MAT'L: 000 200 118 240, P/N: 49GR. 5312- 07, DWG: 454-0-004063FOR HP SHAFT ON IMP ELLER,SERKO-1, MAKER: MAN	Support radial loads Allow for dynamic movement and misalignments Provide stability during operation	- Fracture or fatigue of tilting pads - Misalignment leading to uneven wear - wear and tear on the bearing surface - Insufficient lubrication causing friction and overheating	High Vibration, High Temperature Catastrophic	Interlock Control, Routine Inspection	10	6	5	300	HIGH	
A	110001001	MECHANICAL	Bearing	RADIAL TILTING PAD BEARING STAGE 3 BEARING NO.8, MAT'L: 000 010 753 142P/N: 65, GR. 5212-4-MP, CODE: 5212-90SERKO-1, MAKER: MAN	Support radial loads Allow for dynamic movement and misalignments Provide stability during operation	- Fracture or fatigue of tilting pads - Misalignment leading to uneven wear - wear and tear on the bearing surface - Insufficient lubrication causing friction and overheating	High Vibration, High Temperature Catastrophic	Interlock Control, Routine Inspection	10	6	5	300	HIGH	
A	11000080	MECHANICAL	Bearing	RADIAL TILTING PAD BEARING STAGE 4 BEARING NO.7, MAT'L: 000 010 753 141P/N: 66, GR. 5212-4-MP, CODE: 5212-90SERKO-1, MAKER: MAN	Support radial loads Allow for dynamic movement and misalignments Provide stability during operation	- Fracture or fatigue of tilting pads - Misalignment leading to uneven wear - wear and tear on the bearing surface - Insufficient lubrication causing friction and overheating	High Vibration, High Temperature Catastrophic	Interlock Control, Routine Inspection	10	6	5	300	HIGH	
A	10000570	MECHANICAL	Bearing	Trust bearing for bull gear shaft on motor side P/N 69 GR.5212-1Dwg.No:452	Support axial loads Ensure proper alignment of the bull gear shaft Facilitate smooth rotation of the shaft	- Fracture or fatigue of bearing components - Misalignment leading to uneven wear - wear and tear on bearing surfaces - Excessive axial movement	High Vibration, High Temperature Catastrophic	Interlock Control, Routine Inspection	8	5	5	200	MEDIUM	
A	11000430	MECHANICAL	Bearing	THRUST BEARING GR-5212-POS-1-69 (FOR BULL GEAR SHAFT OR MOTOR SIDE) 4101	Support axial loads Ensure proper alignment of the bull gear shaft Facilitate smooth rotation of the shaft	- Fracture or fatigue of bearing components - Misalignment leading to uneven wear - wear and tear on bearing surfaces	High Vibration, High Temperature Catastrophic	Interlock Control, Routine Inspection	8	5	5	200	MEDIUM	

4.4.2 Implementing Multi Criteria Decision

The second improvement is to develop a spreadsheet form as shown at Table 18, used to determine the appropriate stock model based on the established criteria. The stock model selection is done automatically using a matrix which is refer to the models that created in section 4.3.1 until 4.3.4 (see Figure 17).

Table 19. MCDM Spread sheet form

MCDM RESULT									
Main Unit : Air Compressor				MCDM number:		1			
Sub Unit : Air Compressor Stage 1-5				Page :		1 of 1			
Core Team Mr. B, Mr. C, Mr. D				MCDM Date		17/11/2023		Rev:	
Material Code	S/P Criticality	Lead Time	Lead Time Rank	S/P Unit Price	Price Rank	Model Stock	Decision	Proposal Quantity	Remark
110001001	HIGH	18	HIGH	56580,35	HIGH	Model 1	Stock	1	
11000080	HIGH	18	HIGH	56580,35	HIGH	Model 1	Stock	1	
11001350	HIGH	6	HIGH	10313,4	HIGH	Model 1	Stock	1	
11001520	HIGH	12	HIGH	597,61	LOW	Model 1	Stock	1	
11001510	HIGH	12	HIGH	571,17	LOW	Model 1	Stock	1	
10000150	HIGH	12	HIGH	566,1	LOW	Model 1	Stock	1	
10000240	HIGH	12	HIGH	244,45	LOW	Model 1	Stock	1	
100000801	HIGH	18	HIGH	2,07	LOW	Model 1	Stock	1	
100000901	HIGH	18	HIGH	4,45	LOW	Model 1	Stock	1	
10000130	HIGH	10	HIGH	86,33	LOW	Model 1	Stock	1	
10000140	HIGH	8	HIGH	58,09	LOW	Model 1	Stock	2	
11001390	HIGH	6	HIGH	30,65	LOW	Model 1	Stock	2	
10000170	HIGH	12	HIGH	541,55	LOW	Model 1	Stock	1	
10000180	HIGH	7	HIGH	73,85	LOW	Model 1	Stock	1	
10000190	HIGH	8	HIGH	97,26	LOW	Model 1	Stock	1	
10000250	HIGH	12	HIGH	6,09	LOW	Model 1	Stock	1	
10000280	HIGH	12	HIGH	9122,08	HIGH	Model 1	Stock	1	
10000290	HIGH	12	HIGH	686,58	LOW	Model 1	Stock	1	
10000330	HIGH	12	HIGH	753,42	LOW	Model 1	Stock	1	
10000360	HIGH	5	HIGH	122,16	LOW	Model 1	Stock	1	
10000370	HIGH	5	HIGH	383,24	LOW	Model 1	Stock	1	
10000530	HIGH	18	HIGH	41996,95	HIGH	Model 1	Stock	1	
10000540	HIGH	18	HIGH	41624,51	HIGH	Model 1	Stock	1	

High Criticality		Price		
Lead Time	High	Medium	Low	
	High	Model 1	Model 1	Model 1
	Medium	Model 1	Model 1	Model 2
Low	Model 1	Model 2	Model 3	

Medium Criticality		Price		
Lead Time	High	Medium	Low	
	High	Model 1	Model 1	Model 1
	Medium	Model 1	Model 2	Model 3
Low	Model 3	Model 4	Model 4	

Low Criticality		Price		
Lead Time	High	Medium	Low	
	High	Model 3	Model 3	Model 3
	Medium	Model 3	Model 3	Model 3
Low	Model 4	Model 4	Model 4	

Figure 17. Stock Model Matrix

4.4.3 Result of Systematically Approach

Systematic approaches help reduce errors and improve accuracy. When tasks are carried out in a structured manner, there is less room for oversight or mistakes. It's promoted consistency in decision-making and actions. This is crucial for ensuring uniformity in processes, especially in areas where standardization is important. The methodology that has been created above is incorporated into the standard operating procedure as a reference for all engineers responsible for managing the spare part inventory.

The outcomes observation of this systematic approach was applied to the Spare Parts Unit for the Air Compressor, which is registered in the warehouse system, through simulation using Microsoft Excel. It comprises a total of 539 material codes utilized to fulfil the requirements of two typical air compressor units across both factories. The current total inventory value stands at 4.3 million USD which is consist of mechanical part 3.7 million USD, electrical parts 0,38 million USD and instrumentation parts 0,20 million USD. The complete assessment attached at the end of this thesis.

4.5 Control

The control phase involves evaluating the outcomes of the improvement. If the results of the improvement are still not satisfactory, it is advisable to return to the Analysis phase for a reassessment of the design improvements. Once the improvements align with the expected results, the subsequent stage is the sustainability project.

4.5.1 Assessment Result Examination

The outcomes of the examination utilizing the systematic multi-criteria decision method reveal that the urgency for spare parts' immediate availability in case of an issue is reflected in the abundance of stock model-1 at 67%, stock model-2 at 4%, and stock model-3 at 29%. This distribution is reasonable, especially considering the high criticality classification of this air compressor unit as shown at Table 20.