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Inventory Analysis using Multi-Criteria ABC and ISM Method – A Case Study in Indonesia's Aviation MRO

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Abstract

Level of inventory plays a crucial role in managing the supply chain in a company, one of which is Aircraft Maintenance, Repair, and Overhaul (MRO) Company. This paper will analyze the material inventory in one of Indonesia's aircraft MRO companies by categorizing the material and focus on finding the root causes of the high inventory level. ABC Analysis using multiple criteria will be used to categorize the aircraft spare parts inventory. The categories will then be used as the Focus Group Discussion (FGD) topic to gain and determine several root causes of the phenomena. FGD results will then be further analysed using Interpretative Structural Matrix (ISM) to see if there are some interrelationships between root causes. The high inventory level of aircraft spare parts inventory root causes will be specifically determined by analyzing the A category of ABC Classification as this category represents 70% of the inventory. Based on the analysis, it is recommended to solve the root causes extracted from the ISM first to lower the inventory level. This study will be useful for managers to determine the strategy to make the inventory lower impacting on the increase of company's profit increase.

Keywords: ABC Classification, Interpretive Structural Matrix, Inventory, MRO, Root Cause Finding.

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1. Introduction

In the time of the Pandemic COVID-19, the aviation business was impacted significantly that some aviation company struggled and suffered from economic loss (IATA, 2022). Airline business then shows recovery in international air travel and were resilient to shocks, but the market in Asia Pacific is still struggling (IATA, 2022). The pace of that recovery, however, continued to diverge between Asia-Pacific and the rest of the world, although some Asia-Pacific markets, such as Australia, have begun recovering faster than the region overall following their governments' relaxation of restrictions (IATA, 2022). This phenomenon impacted the operational side of aviation business, which the businesses is Maintenance, Repair, and Overhaul (MRO) for airplanes, which underwent a Return of Investment (ROIC) loss of 5% in 2020 (IATA, 2022). Today, the aviation business has shown some recoveries along with the subsiding of COVID-19 Pandemic. The demand for airplanes repair and overhaul increases and predicted to be fully recovered in 2024, with predicted annual growth of 2.8% (Prentice et al., 2022).

In an MRO, its inventory sought as the parts that support the production operations but not included in the finished product (Chen, Gusikhin, Finkenstaedt, & Liu, 2019). Parts include consumables, asset maintenance supplies, and spare parts (Chen et al., 2019). The demand and the supply of these parts are maintained by the supply chain group of the company, namely the planning and purchasing department. Material spare parts are needed to fulfill the appropriate aircraft repair activities with requests from production and maintenance type planning for each aircraft. Spare parts materials are crucial and are expected to always be precise its use so that it does not become immovable inventory or become a cost additional cost to the company due to errors that occur in chain management supply of aircraft spare parts (Harimansyah & Imaroh, 2020).

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PT XYZ, as one of Indonesia's biggest aviation MRO is now facing an inventory problem. One of the phenomena that often occurs in the company PT XYZ is the inaccuracy of inventory planning which contributes to the increase in the company's inventory as a result of purchases that have not been effective and efficient.

The objective of this paper is to study the characteristics of PT XYZ aircraft inventory material to find the root cause of planning inaccuracy which resulted in the high level of the company's inventory. Previous studies, such as weight linear optimization approach for muticriteria ABC inventory (Torabi, Hatefi, & Pay, 2012), regression-based improvement to the multiple criteria ABC inventory classification (Karagiannis & Paleologou, 2021), and multi-criteria ABC inventory classification with exponential smoothing (Jamshidi & Jain, 2008a) have conducted inventory classification, however the classification has been used only to determine the characteristics of the materials in inventory. The characteristics have not been used to further be analysed such as the root cause of high inventory in specific characteristics of the inventory. This paper will elaborate the the root cause of the high inventory level from Category A of the inventory, so that it will be useful by the management as a tool for their company's inventory analysis. Firstly, the paper will provide a literature review of the research, focusing in classification of the aircraft spare parts, inventory of aviation, and method of root cause finding using Cause-Effect Diagram and Interpretative Structural Matrix. Secondly, through analyzing PT XYZ aircraft spare parts data and finding the root cause using FGD, we aim at analyzing the root cause of planning inaccuracies in PT XYZ and finding the right strategies to better planning of the inventory.

The remaining of this paper is as follows. Section 2 provides a theoretical review of studies addressing spare parts classification, forum group discussion to find the cause-effect diagram, processing the result using interpretative structural matrix, the integration with inventory management and the gap between research and practice in planning the aircraft spare parts inventory. Section 3 describes the methodology for empirical research. Section 4 presents the findings from the aircraft spare parts classification and findings from the FGD-CED-ISM, comparing to current inventory management condition of PT XYZ. In section 5, the results are discussed and points out some conclusive remarks and the limitations of this research.

2. Literature Review

2.1. Inventory Management in MRO

Maintenance, Repair, and Operations (MRO) are inventories that support production operations but are not included in the finished product . Spare parts in MRO consist of consumables, asset maintenance supplies, and spare parts (Chen et al., 2019). The two main reasons for storing MRO inventory are to obtain economic value when purchasing and to avoid material shortages which can impact production activities (Heizer, Render, & Munson, 2020). Although the demand for MRO supplies is often a function of the maintenance schedule, unscheduled requests must also be anticipated (Heizer et al., 2020).

2.2. Inventory Management in MRO

In general, inventory analysis using the ABC method divides on-hand inventory into three classifications based on annual dollar volume (Heizer et al., 2020). The division of the ABC classification is divided into: A – very important; B – more important; and C - relatively less important, as a basis for controlling inventory. Heizer et al., (2020) stated that each category has different characteristics so that the treatment for each is different. Category A is goods that represent 15% of the total inventory volume but represents 70%-80% of the total cost usage, category B represents 30% of the total volume and 15%-25% of the total cost usage (medium annual dollar volume) , and category C represents 5% of the total cost usage (low annual dollar volume) but represents 55% of the total inventory volume. To obtain a more accurate classification, ABC classification using multi-criteria has been introduced, using three criteria, namely annual dollar usage, number of hits, and average value per hit (Jamshidi & Jain, 2008). Weight of each criteria will be determined using Pairwise Comparison, taken from the judgement of the experts. This method is used to get a quantified weight from qualitative data, that is the judgements from experts.

The discussion of inventory management, especially in the classification of materials and spare parts has been widely used with various methods and various business fields. To classify spare parts in this study, the model used in a research journal conducted by Jamshidi & Jain (2008) concerning the ABC Classification of inventory using multiple criteria is used. The multi-criteria ABC classification based on three assessments (criticality, number of hits, and annual dollar usage), as well as using exponential smoothing and management models must be arranged into material in classification A because this classification is the most critical according to Jamshidi & Jain's research (2016).

Other research related to the classification of spare parts has been carried out by Ng (2007) using a linear weight optimization model, by converting all measurements to a scalar scale. Zhou & Fan (2007) in their research carried out an extension of multi-criteria ABC using the R-model to determine which items are prioritized. Research by Bacchetti & Saccani (2012) classifies spare parts using a simple monocriteria classification method for spare parts management. Research by Pérez Vergara et al. (2020) weighted the multi-criteria classification of ABC using the AHP technique. Karagiannis & Paleologou (2021) used a regression-based approach to derive a set of weights for analyzing ABC multicriteria in inventory.

2.3. Inventory Management in MRO

Root Cause Analysis used as a tool to identify root causes of problems or defects (Council Six Sigma, 2018). A popular method for brainstorming and analyzing causation in a process is the fishbone diagram, where it lets teams concentrate on a brainstorming process that generates idea about possible problem causes, organizes those possibilities between ideas (Council Six Sigma, 2018).

To further analyze the root cause of the phenomena, interpretative structural matrix (ISM) will be used in this research. ISM is a modelling technique proposed by Warfield (1974), a methodology assisted by computer used in constructing and understanding elementary relationships of elements in complex situations or systems (Tzeng & Huang, 2011). Interpretative Structural Matrix will show the hierarchal cause-effect relationships between potential causes and maps them into quadrants (Abellana, 2021). Finally, those potential causes in particular quadrant will be the main causes of the phenomena.

3. Methods

The research takes place at PT XYZ, a subsidiary of PT AB which business is in aviation. PT AB is the national airline of Indonesia, while PT XYZ is the MRO Facility for PT AB and other third parties airline. PT XYZ’s business covers the maintenance of airplanes, their engines, and other businesses which support the operation of the aircraft itself. The types of aircraft maintained in PT XYZ are the narrow-bodied aircraft (such as Boeing 737 series, Airbus A320 series, ATR 72 series) and wide-bodied aircraft (Boeing 777 series, Airbus A330 series, Boeing 747 series). Customers are coming not only from Indonesia and PT AB, but also from every part of the world such as Asia, Europe, America, and Australia.

The research used is a combination of qualitative and quantitative method, based on the results of interviews/FGDs with related parties and data obtained through the ERP system used by PT XYZ. The research will focus on the type of consumables material for the Boeing 737-800NG aircraft type which performs maintenance at PT XYZ. This type of material was chosen for further analysis due to the relatively high amount in PT XYZ's inventory and the type of consumables material which has a disposable character, so that if the shelf life has expired, the material will go into the scrap process. The Boeing 737-800NG type aircraft was chosen as the type of aircraft being analyzed because the number of aircraft with that type is the most frequently maintained at PT XYZ.

Analysis will be carried out using multi-criteria ABC classification with 3 criterias based on the study of Jamshidi & Jain (2016), where the inventory is classified based on the annual dollar usage, the number of hits per item, and the average value per hits. This method was chosen because the calculation is relatively easy to apply in industry, especially in aviation, and not as complicated. The root cause finding method using FGD and CED was chosen to get to know the inventory problem deeper from the company’s experts and to map out the problems from the view of 5M (Man, Material, Method, Machine, Mother Nature).

The stages of research are needed as a guide for the activities to be carried out. The research was aimed at classifying PT XYZ's spare parts inventory, especially consumables spare parts for the Boeing 737-800NG aircraft type. This research will focus on classifying Boeing 737-800NG material consumables using the ABC multiple criteria classification method, comparing the previous classification with the classification using the multi-criteria method, and then analyzing the problems that cause overplanning using the root cause analysis of the Causal-Effect Diagram – Interpretative Structural Model (CED- ISM) through a focus group discussion process.

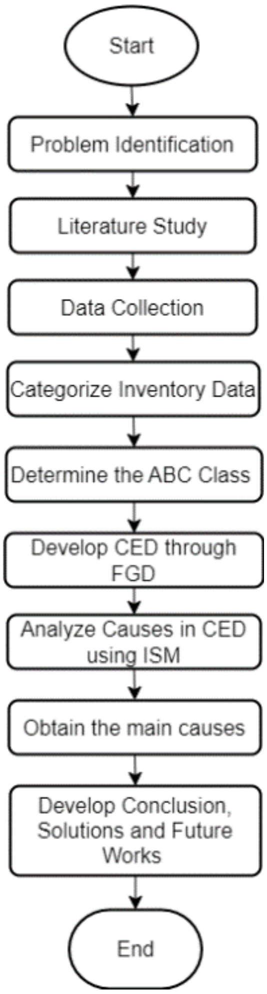

Figure 1. Research Flow Diagram

3.1. Inventory Classification using Multicriteria ABC Analysis and AHP – Pairwise Comparison

The inventory data obtained will be classified into ABC using the weight of three criteria: (1) Annual Dollar Usage; (2) Number of hits; and (3) Average dollar per hits (Jamshidi&Jain, 2008). These criteria have different unit of measurements, a standatdization of data will be applied to each of the criteria using the formula (Jamshidi&Jain, 2008):

$$Standardized\ Value = N_{ij}/L_i \qquad (1)$$

$N_{ij} = item\ j\ in\ criteria\ i$

$L_i = largest\ value\ in\ criteria\ i$

The weight of these three criteria is determined by obtaining 5 expert judgements from PT XYZ and further be calculated using AHP – Pairwise Comparison method. Different weight will be applied to each criteria. In determining the weight, these experts will give their judgement of each criteria using the AHP Scale developed by Saaty (1987) ranging from 1-9 which represents Equal Importance to Extreme Importance.

The obtained judgements per criteria will be processed using geometric arithmetic mean. To determine the weight of each criteria, we use eigenvalue problem solution:

$$A\omega = \lambda_{max}\omega \qquad (2)$$

Where A is an n dimensional of the comparison matrix, λ_max is the largest eigenvalue of A, and "ω" is the eigenvector corresponding to λ_max (Pérez Vergara et al., 2020). The consistency and accuracy of the weighting will be seen using

Consistency Ratio (CR), which is the product of division of Consistency Index (CI) by Random Consistency Index (RI). CR shall be below 10% for a reliable result.

$$CR = \frac{CI}{RI} \quad (3)$$

$$CI = (\lambda_{max} - n) / (n - 1) \quad (4)$$

Table 1. The profile of the 5 experts

Name	Position	Years of Experience
A	Manager of Material Planning	7 Years
B	Senior Material Planner	6 Years
C	Manager of Material Purchasing	7 Years
D	Senior Manager of Inventory and Storage of Material	7 Years
E	Material Inventory Controller	2 Years

Table 2. Fundamental scale in Pairwise Comparison

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement strongly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgement	When compromise is needed

Source: The analytic hierarchy process-what it is and how it is used (Saaty, 1987)

3.2. Root Cause Analysis using Hybrid of CED - ISM

To obtain potential causes, this research uses focus group discussion (FGD) among Supply Chain experts. FGD will also be used to determine the causal relationships between potential causes. Determination of the root cause uses the hybrid of Cause-and-Effect Diagram development and the Interpretative Structural Matrix procedure as referenced in the research of (Abellana, 2021). The steps are as follows.

Step 1: Develop a Focus Group Discussion (FGD). FGD is conducted one time for the duration of 2 hours, focusing on finding the causes of high inventory using 5M (Man, Material, Method, Machine, Mother nature) and the contextual relationship between causes. The output will be points of potential causes of high inventory and their relationships.

Step 2: Develop a contextual relationship between causes into structural self-interaction matrix (SSIM) using VAXO notation for each relationship.

Table 3. VAXO Notation for Structural Self-Interaction Matrix

Linguistic Scale	Does factor A cause factor B?	Does factor B cause factor A?
V	Yes	No
A	No	Yes
X	Yes	Yes
O	No	No

Source: A proposed hybrid root cause analysis technique for quality management (Abellana, 2021)

Step 3: Develop the initial reachability matrix, which formed by replacing the notation in SSIM with 1s and 0s with the rules:

Table 4. Notation for Initial Reachability Matrix

SSIM Notation	(i,j) Entry	(j,i) Entry
V	1	0
A	0	1
X	1	1
O	0	0

Source: A proposed hybrid root cause analysis technique for quality management (Abellana, 2021)

Step 4: Determine the Final Reachability Matrix by determining if there is a transitivity in the matrix (if A leads to B and B leads to C< then A leads to C), and obtain the dependence and driving powers by summing each row (as driving power) and column (as dependence power).

Step 5: Cluster the causes into MICMAC analysis (driving-dependence map). Map will be divided into 4-quadrants, that is Driving, Linkage, Autonomous, and Independent.

Table 5. Categories of Variables

Categories	Driving Power	Dependence Power	Characteristics
Autonomous	Low	Low	Variables do not affect the system
Linkage	High	High	Variables cause instability of the system. Any action on these variables will cause volatility in the system
Independent	High	Low	Strongly influences the system but is not influenced by it.
Dependent	Low	High	Strongly influenced by the system but does not influence the system.

Source: Interpretive Structural Modeling (ISM) and its application in analyzing factors inhibiting implementation of Total Productive Maintenance (Poduval, Pramod, & Jagathy Raj, 2015)

Step 6: Causes in the Driving and Linkage quadrant will be the main root cause of the problem and solution of the problem will be determined using these root causes. Causes in Driving and Linkage provides sufficient driving powers to be considered as "causes", while causes in Dependence have a very low driving power and causes in Autonomous do not interact with the system.

4. Result and Discussions

4.1. Inventory Classification Using Multi-Criteria ABC Classification

The weight of each criteria is extracted using the Pairwise Comparison from 5 of the expert judgement from planning, purchasing and inventory management of PT XYZ. The weight of each category is as follows:

Table 6. The weight of each criteria used for Multicriteria ABC Analysis

Criteria	Weight
Annual Dollar Usage	0.328
Number of Hits	0.411
Average Dollar per Usage	0.261

With these weight per category, we can now determine the ABC of each item in the inventory by multiplying the standardized value in each criteria with its weight. Items in category A are used as the basis of FGD data, to determine the possible root causes of high inventories.

Table 7. Sample of 10 items in Category A

Part Number	Number of Hits	Annual Usage	Average Value Per Hit	Pairwise Comparison	Classification
CH31900-6:0AFL4	204	$178,653.64	874.3245	0.5361	A
HLX64621:017J3	414	$4,159.41	10.0388	0.4190	A
3011:08806	385	$31.17	0.0809	0.3826	A
NAS1097KE6-8:80205	375	$119.12	0.3174	0.3728	A
7577741:05228	362	$5,536.98	15.2815	0.3700	A
BACS38K1:81205	292	$7.53	0.0258	0.2896	A
31-9292-2:72914	0.3	$14,375.77	43127.3100	0.2877	A
BACS12GR3S16:60516	280	$2,901.80	10.3636	0.2834	A
CSR904B5E5:81205	262	$1,869.33	7.1439	0.2632	A
M83485-1-008:81349	258	$74.83	0.2897	0.2566	A

4.2. Root Cause Finding Using Hybrid CED-ISM

From this classification, we analyze the inventory condition of these items. It was found that every item in Category A had remaining inventory from the purchase in 2020-2022. Taking the example of item part number CSR904B5E5:81205, PT XYZ purchased 137 EA of this part number, but it was not moving nor used until February 2023. Similar condition happened to the other items in Category A, where there was a purchase of a number of quantity, but it was not used or not fully used by February 2023. From this condition, we want to know the root cause of this phenomenon by performing an FGD with the 5 experts of Material Supply Chain area in PT XYZ. The forum lasts 1.5 hours with the discussion of the potential root cause of the phenomenon (seen from the 5M perspectives) and finds out the causal relationship between the potential root causes.

Table 8. Number of remaining inventory in Sample of 10 items in Category A

Part Number	Classification	Remaining Inventory from 2020-2022 purchase
CH31900-6:0AFL4	A	37
HLX64621:017J3	A	16
3011:08806	A	50
NAS1097KE6-8:80205	A	20
7577741:05228	A	10
BACS38K1:81205	A	2
31-9292-2:72914	A	10
BACS12GR3S16:60516	A	90
CSR904B5E5:81205	A	137
M83485-1-008:81349	A	86

Table 9. Potential Root Causes of High Inventory Level in Category A

No	Potential Root Cause	5M Category
1	Lack of Knowledge	Man
2	Lack of Awareness	Man
3	Minimum Quantity Order applied from vendor	Material
4	Lack of Task List Accuracy	Material
5	Lack of Evaluation	Method
6	System Inaccuracy	Machine
7	Supply Chain Disruption	Environment

After determining these potential root causes, the FGD continues to find the relationships between these 7 potential root causes. Using the VAXO notation to evaluate the relationship, the SSIM matrix can developed to describe the causal relationship among them.

Table 10. SSIM Matrix for the relationships between potential root causes

Potential Root Cause No.	7	6	5	4	3	2	1
1	O	V	V	V	O	X	
2	O	V	X	V	A		
3	A	O	O	O			
4	O	V	A				
5	O	V					
6	A						
7							

The SSIM is converted to an Initial Reachability Matrix which shows the pairwise relationship in binary of 1 and 0. After converting into binary, the Initial Reachability Matrix is further be analysed if there is any transitivities, which then be presented in Final Reachability Matrix.

Table 11. Initial Reachability Matrix

Potential Root Cause No.	1	2	3	4	5	6	7
1	1	1	0	1	1	1	0
2	1	1	0	1	1	1	0
3	0	1	1	0	0	0	0
4	0	0	0	1	0	1	0
5	0	1	0	1	1	1	0
6	0	0	0	0	0	1	0
7	0	0	1	0	0	1	1

Table 12. Final Reachability Matrix with Driving and Dependence Power calculated

Potential Root Cause No.	1	2	3	4	5	6	7	Driving
1	1	1	0	1	1	1	0	5
2	1	1	0	1	1	1	0	5
3	1*	1	1	1*	1*	1*	0	2
4	0	0	0	1	0	1	0	2
5	0	1	0	1	1	1	0	4
6	0	0	0	0	0	1	0	1
7	0	1*	1	0	0	1	1	3
Dependence	2	4	2	4	3	6	1	

MICMAC Quadrant can be developed by plotting each of the potential root cause into the quadrant graph to see whether it is categorized as Independent/Linkage/Autonomous/Dependent.

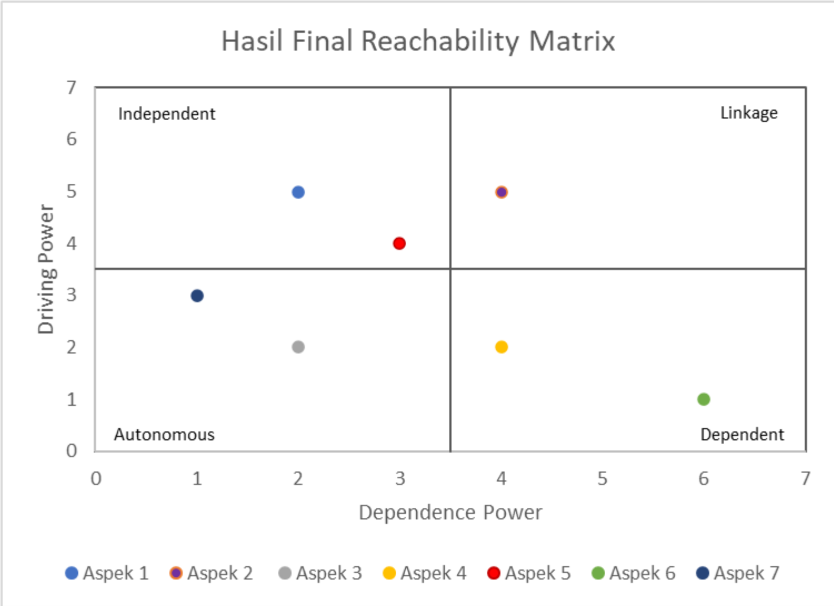

Figure 2. MICMAC Quadrants Grap

Table 13. The result of MICMAC categorization of each potential root causes

Potential Root Cause No.	Name	MICMAC Category
1	Lack of Knowledge	Independent
2	Lack of Awareness	Linkage
3	Minimum Order Quantity applied by the vendor	Autonomous
4	Lack of Task List Accuracy	Dependent
5	Lack of Evaluation	Independent
6	System Inaccuracy	Dependent
7	Supply Chain Disruption	Autonomous

It can be extracted from the MICMAC that Aspect 1 (Lack of Knowledge), Aspect 2 (Lack of Awareness), and Aspect 5 (Lack of Evaluation) as the main root cause of the high inventory at PT XYZ. These three aspects are categorized under Independent and Linkage in MICMAC, so that these three aspects have high driving powers. This finding leads us to the conclusion that management should focus on these three factors before looking at other potential causes for the high inventory problem. As a result, management is also able to solve additional problems, but to be economical, it should adhere to the prioritizing established by this study. Strategic suggestions to these three root causes can be made based on the short-term strategies and long-term strategies, such as carrying out material evaluation periodically on inventory leftover, capital readiness development through training (internal and external), and conduct material engineering analyst function.

5. Conclusions

The management of inventory in Aviation MRO differs from other industries as it requires high accuracy so that the aircraft maintenance project can be done on time. The operational side of the aviation MRO depends on the availability of spare part materials, but its level also has to be maintained so that it will not be a waste to the company. A better inventory level means lower costs for the spare parts procurement, that leads to higher quality and higher profits for the company. This research studied the characteristics of PT XYZ inventory, by taking the sample of spare parts from Boeing 737-800NG in the inventory. Categorizing the inventory gave a differentiation between spare parts so that it can be analyzed according to its characteristics. Items in Category A, which have the high number of usages, high annual dollar, and high average dollar per usage are used to be analyzed further because of the items in this category is more important than those in B and C.

As a result, items in Category A have plenty of remaining quantity from the inventory, which contributes to unmoved value for the company. To solve this problem, we analyzed it further using FGD and the Interpretative Structural Matrix to see some potential causes and its relationship between them.

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