NETWORK SPARE-PART MANAGEMENT USING CLASSIFICATION MATRIX

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ABSTRACT

Network spare-part inventory management is an important factor to ensure a successful network management service. A well managed spare part inventory allows business to operate with efficiency, and lower the business operation cost. Therefore, finding a suitable network spare-part model inventory is important for network services provider. By finding the balance of having enough spare part to ensure that there is always available spare part when needed without having to keep excessive amount of it in the inventory. A good inventory management model help to classify items based on the characteristic of the item in the inventory, this help create policy to manage each spare part item in the inventory. When doing research on this topic, a few studies have been done on network spare part management model, therefore the goal of this thematic paper was to find a suitable network management model for managing last-mile network equipment.

KEY WORDS: NETWORK / SPARE PARE MANAGEMENT/ INVENTORY CLASSIFICATION / MATRIX

32 pages

การบริหารจัดการชิ้นส่วนสำรอง ของอุปกรณ์เครือข่ายโดยเมทริกการจำแนกประเภท
NETWORK SPARE-PART MANAGEMENT USING CLASSIFICATION MATRIX

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บทคัดย่อ

การบริหารจัดการชิ้นส่วนสำรอง ของอุปกรณ์เครือข่ายเป็นส่วนสำคัญ ส่วนหนึ่งของการให้บริการของเครือข่ายนั้น การจัดการชิ้นส่วนสำรองที่ดีนั้นช่วยให้ธุรกิจดำเนินงานได้อย่างมีประสิทธิภาพ และ ช่วยลดต้นทุนในการดำเนินธุรกิจ ดังนั้นรูปแบบการจัดการที่เหมาะสม เป็นส่วนสำคัญส่วนหนึ่งที่ผู้ให้บริการเครือข่ายควรคำนึงถึง โดยการหาสมดุลระหว่าง การเก็บอะไหล่ให้พอเพื่อให้แน่ใจว่ามีอะไหล่เพียงพอเมื่อมีความต้องการในการใช้งาน แต่อะไหล่ที่เก็บนั้นก็ไม่ควรมีจำนวนมากเกินไป รูปแบบการจัดการสินค้าคงคลังที่ดีจะช่วยในการจำแนกชิ้นส่วนสำรอง ตามลักษณะขอชิ้นนั้นๆ เพื่อช่วยในการสร้างนโยบายในการจัดการของอะไหล่แต่ละชิ้น ตอนที่ค้นหาหัวข้อการวิจัยนั้น ได้พบว่าบทความที่เกี่ยวข้องกับรูปแบบการจัดการชิ้นส่วนสำรองของอุปกรณ์เครือข่ายมีค่อนข้างน้อย วิทยานิพนธ์นี้มีวัตถุประสงค์เพื่อหารูปแบบการจัดการชิ้นส่วนสำรองของอุปกรณ์เครือข่ายที่เหมาะสมสำหรับการจัดการอุปกรณ์เครือข่ายปรายทาง

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CHAPTER I
INTRODUCTION

1.1 Background and Problem Statement

In maintenance service, spare part considered to be one of the most important aspects along with: specialist, mechanical engineer, and tools and equipment. Many operators rely on high-value assets to provide services or goods to their customers. Down time in the production or service can result in lost of revenues, customer complaint, penalty, or public safety. Consequently, to ensure spear parts are available when needed, companies both dedicated internal and external resources to spare part management [1,2].

Spear parts inventory management play a crucial part in running a successful service operation, when availability and continuity of the service are priority. Therefore, it is the responsibility of service provider to ensure businesses and services run without interruption. Because if there are not enough spear part when needed, service provider would not be able to meet the SLA agreeing with the customer. This could result in fine, and low customer satisfaction. On the other hand, having excessive amount of spear-part would affect the firm’s profit. As company needs to bare the excessive cost of inventory, opportunity cost, and the risk of spare parts being obsolete. Therefore, balancing between having excess spare part and not having enough spare part in the inventory is crucial for service provider and operator [2, 3].

Different company adopt different inventory policies to optimize inventory amount, order quantity, reorder point, and inventory management strategy. To minimize inventory cost, companies hold the least amount of inventory as they possibly can to meet customer needed, or SLA [3].

In this study, we look at the spare part management model of the last-mile network of a government agency under the Ministry of Education, Uni-Net. Uni-Net is a government agency under the Office of Higher Education Commission, Ministry of Education wo is responsible to manage the information technology and communication for universities, schools, and agencies under MOE. The agency mission is:

1. To develop the networks infrastructure, information technology, and intercommunication among educational institutions for both domestic and international organizations.

2. To managing the network infrastructure and communication technology for education, research and development [4].

The main responsibility of Uni-Net is to provide the Internet connection to schools, universities, and educational agencies across Thailand. The International links are interconnected to local network gateway, backbone network, and distribution nodes to provide Internet connectivity to public schools of the nation. The last mile link is connected to distribution node. Network equipment in the last-mile network consists of router, switch, media converter, and UPS.

To maintain availability of service to the customers, network system need both preventive and corrective maintenance. Preventive maintenance is done for 4 times a year to ensure the equipment fit for use. Corrective maintenance is done when the equipment malfunction. The spare part is crucial when it comes to corrective maintenance, because the right part must be available when needs. Thus, spare part management play an important role in service continuity and availability.

1.2 Objectives

The objective of this study is to find a suitable network spare part inventory model to use in the last-mile network management service. By categorizing items in the spare part inventory based on its characteristic.

1.3 Scope of Work

This research will use the data collected from the ticket system, and spare part database from 2013 to 2015. The ticket monitoring system operated by network operations center. The system is used to generate and track incident ticket occurring from last mile network equipment under maintenance agreement. In addition, the data of spare part inventory turnover in during the past 3 years will also be applied in this study.

1.4 Expected Result

To find a suitable spare part model suitable for the management of the last mile network equipment.

CHAPTER II
LITERATURE REVIEW

This chapter will discuss on the research from IEEE Xplore Digital Library and International Journal of Innovative Science Engineering & Technology with key words of “Spare part/ Inventory Management/Inventory Analysis.” From the research, there are several methods used to manage inventory. Each method classified item in the inventory based on it characteristic and classified item into group. It helps us to understand and manage inventory easily. However, every inventory management model has its strength and weakness, so one model that can apply to every scenario. The literature review will look at inventory management method commonly used to manage inventory.

2.1 ABC Analysis

ABC analysis is the most used method to classify the items into three groups (A, B, C), in order of importance. The following parameters are considered for each item

- Total consumption during the reference period
- Unit value in the reference period

The most popular method of inventory classification is the ABC analysis where items can be grouped into 3 categories including A, B, and C. It is based on the “Pareto Principle” by Vilfredo Pareto, or the 80/20 rule. Where 20% of items in the inventory are accountable for 80% of the expenditures. The approach divided inventory in 3 categories based on their relative importance as follows [5,6]:

“A” items are accountable for 70-80% of the total cost in an annual consumption value. Items in this category are crucial and critical spare part in the stock. They are accountable for 10-20% of the total item in the inventory [6].

"B" items are in medium consumption value at 15-20%. They are accountable for 30% of the total inventory [6].

"C" items are the least valuable items accountable for 5-10% of the annual consumption value, but accountable for more than 40% of the total inventory [6].

Table 2.1 Example of Value and Proportion [2]

	Value	**Proportion**
A Goods High Value	70-80%	10%
B Goods Intermediate materials	15-20%	10-40%
C Goods Low value	5-10%	>40%

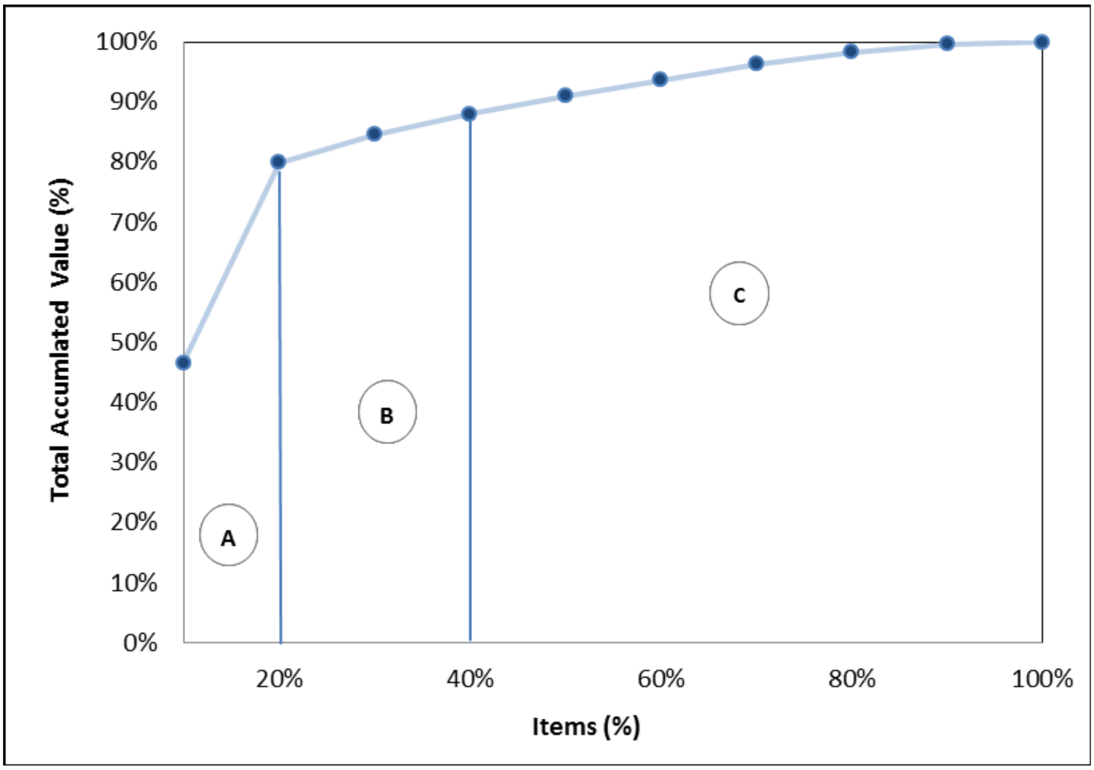

Figure 2.1 ABC Classification. [6]

The goal of the analysis is to classify the inventory into groups inventory policy. It is often use in various fields from medical, sale, and factory inventory management. Inventory policy based on A, B, C classification help to determine how much attention should be given to items. For the high cost A items need to be carefully analyze when setting up a policy more than B. C items which have low cost, little if any analysis is to be done [5, 7]. This ensures that there is a control over the high cost inventory. The policy of each type of item can by summarized as follow:

Table 2.2 ABC Classification Policy

Policy for 'A'	**Policy for 'B'**	**Policy for 'C'**
-Maximum control -Value Analysis -More than one supplier -Control by to executive	-Some control -Regular review	-Minimum control -Bulk Orders -More items from same supplier

The simplicity approach of this method is both its strength and weakness, because items can only classify into three types. Items can be managed easily, but they are limited to 3 categories. ABC analysis calculation is based on empirical values of the limit values and therefore random [5]. As a result, the ABC analysis is often uses with other analysis methods such as, FSN, VDE, and XYZ analysis to add additional perspective to the matrix [8].

2.2 FSN Analysis

FSN classification is a classification method that is based on the consumption rate to 3 types which are fast moving items, slow moving items, and no moving item. Items in the inventory are categorize based on their turnover ratio rate over a given period of time [9].

2.3 VED Analysis

VED classification is a method that classify inventory based on the degree of the criticality of the items. The items are classified based on the effect of not having enough inventory. Items classified as ‘V’ stand for vital , ‘E’ essential, and ‘D’ desirable [10].

2.4 XYZ Analysis

XYZ classification is a method that derives the classification inventory based on predictability of the demand. Items are classified as X when there is a uniform pattern in the demand trend. When the demand of the items is varying, they are classifying as Y. Items are classified as Z when there is abnormality in the demand trend [11].

CHAPTER III
RESEARCH METHODOLOGY

From literature review, we have explored methods that can use classify inventories. But now we will be focus on the classification methods, which we will be applying with our spare-part management. Most classification methods are based on volume, value, or turnover rate of the inventory. They classify items based on the correlation between various attributes. These attributes can be project into the multidimensional scaling matrix, where correlation of each variable can be analyzed easily. We come up with 4 steps to develop a methodology. Firstly, study the existing inventory models for spare-part inventory management.

3.1 Study the inventory models

According to the ABC Classification, there are 3 types of classification under ABC Classification; A, B, and C. Each item is categorized base on the amount of cumulative turnover volume, and the cumulative cost within a given period [6]. The accumulated cost and usage of each item can be plotted to a quadrant graph to see the correlation between the both variables [7].

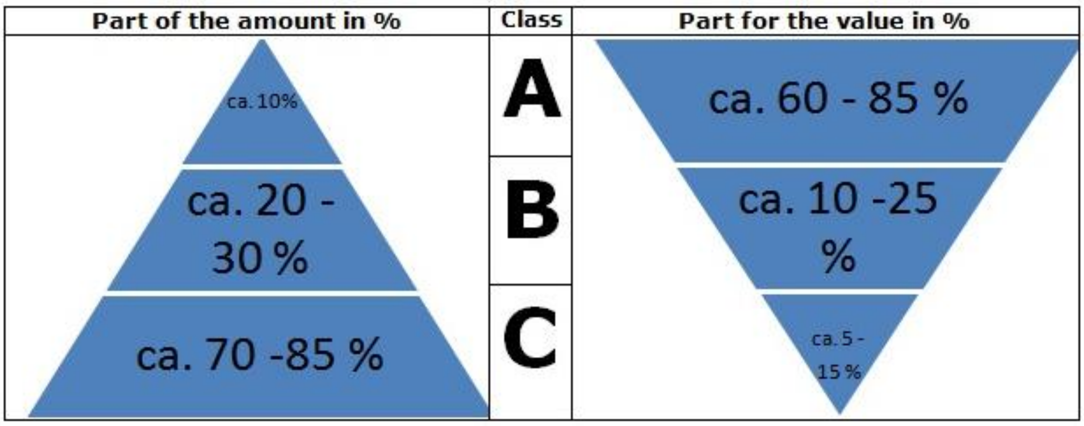

Figure 3.1 Classification sample for three categories.

Figure 3.1 shows comparison of two variables in the ABC analysis. Each variable is represented in the form of percentage ratio.

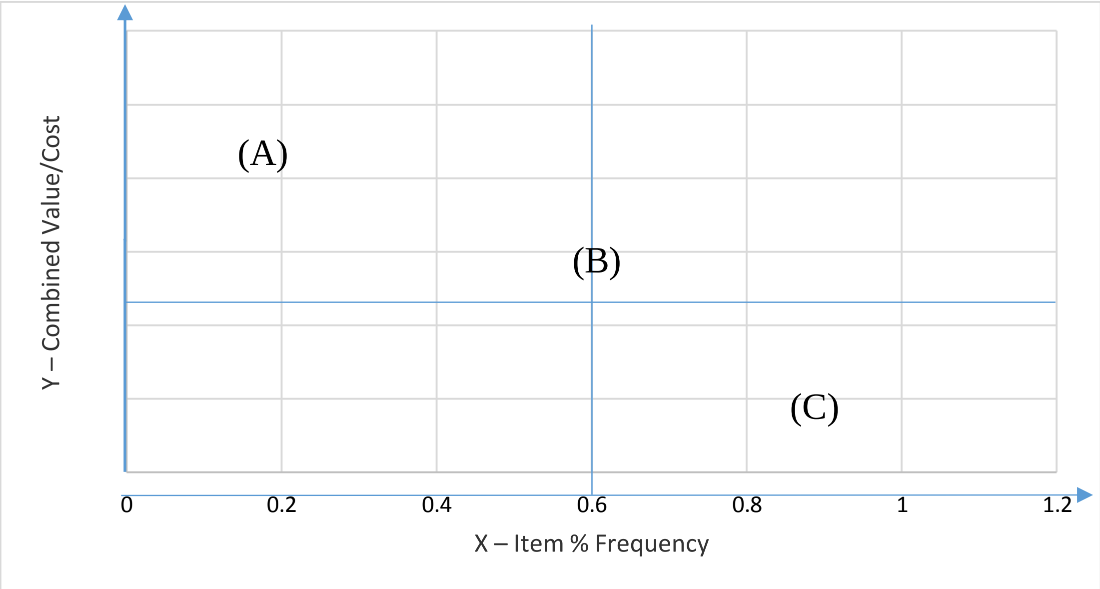

Figure 3.2 ABC Classification Matrix.

Figure 3.1- 3.2 show that under ABC analysis items in the inventory can only be classify into 3 type A, B, and C. Each item is categorized in a fixed area in the quadrants with as follow:

- A items: High Cumulative Cost, Low Usage Frequency
- B items: Medium Cumulative Cost, Medium Usage Frequency
- C items: Low Cumulative Cost, High Usage Frequency

From these given characteristics, a graph can be created with X and Y-axis representing frequency (turnover) and cumulative cost respectively. The correlation between two axes can be inspected and analyzed in a two-dimensional form. However, ABC classification has limitation, when the item does not fall in these 3 categories. For example, item with the high usage may have high unit cost, or item with low usage may has low cost. Therefore, the concept of the ABC analysis can only applicable when items in the inventory can be classified to these 3 groups.

Instead of limiting to classification in a linear regression form, data can be plot into quadrants. Where each quadrant can be group into different clusters where results can be classified in 4 groups as follow:

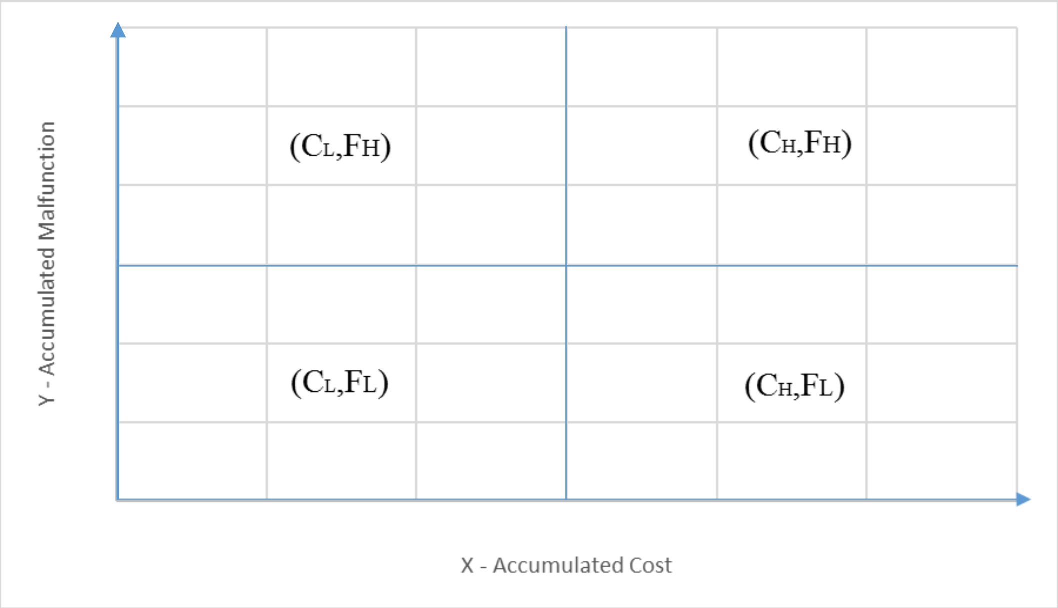

Figure 3.3 Graph representing correlation between cost and frequency.

Figure 3.3 show that data can be plot on to a graph and group into four quadrants. Each item in the graph can be classy into 4 categories.

- Cat1: High Cumulative Cost, High Usage Frequency
- Cat2: High Cumulative Cost, Low Usage Frequency
- Cat3: Low Cumulative Cost, Low Usage Frequency
- Cat4: Low Cumulative Cost, High Usage Frequency

Similarly, the same principle can be applied to graph with another variable. For example, we can change variables to accumulated cost and accumulated malfunction time of the equipment. The data of each item can be plot on to the graph and grouped in quadrants to see the relationship between 2 variables. From the plotted graph, we can categorize each item based on to quadrant it is in.

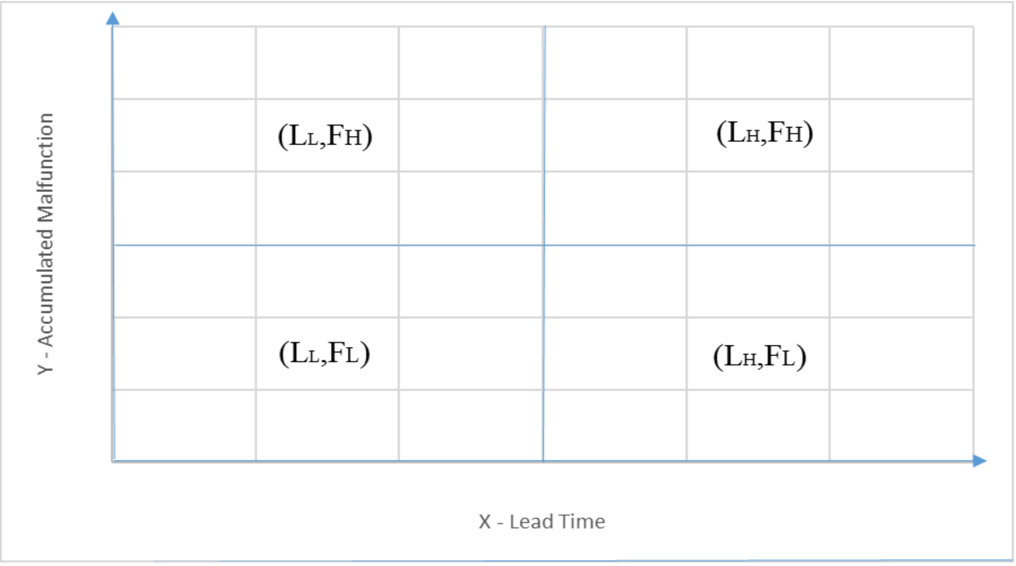

Figure 3.4 Quadrants representing correlation between lead-time and frequency.

Figure 3.4 shown an example of how lead time can also be consider as an optional variable.

- Cat1: High Lead Time, High Usage Frequency
- Cat2: High Lead Time, Low Usage Frequency
- Cat3: Low Lead Time, Low Usage Frequency
- Cat4: Low Lead Time, High Usage Frequency.

Therefore, each item in the spare part inventory can be manage based on the any variable we selected to categories them. Compare to the ABC analysis, this method is more flexible in term of management policy, because of the lower limitation on how items can be categorize.

To further build on this concept we can add additional axis to the existing 2-dimensional graph to create a more complex matrix. Instead of using a 2-dimensional representation with only 2 variables, we can add another axis to add additional variable to the graph. This create a 3-dimensional matrix, with 3 variables, and more categories for item to be categorized in. From this model, allow us to come up a more complex inventory management policy.

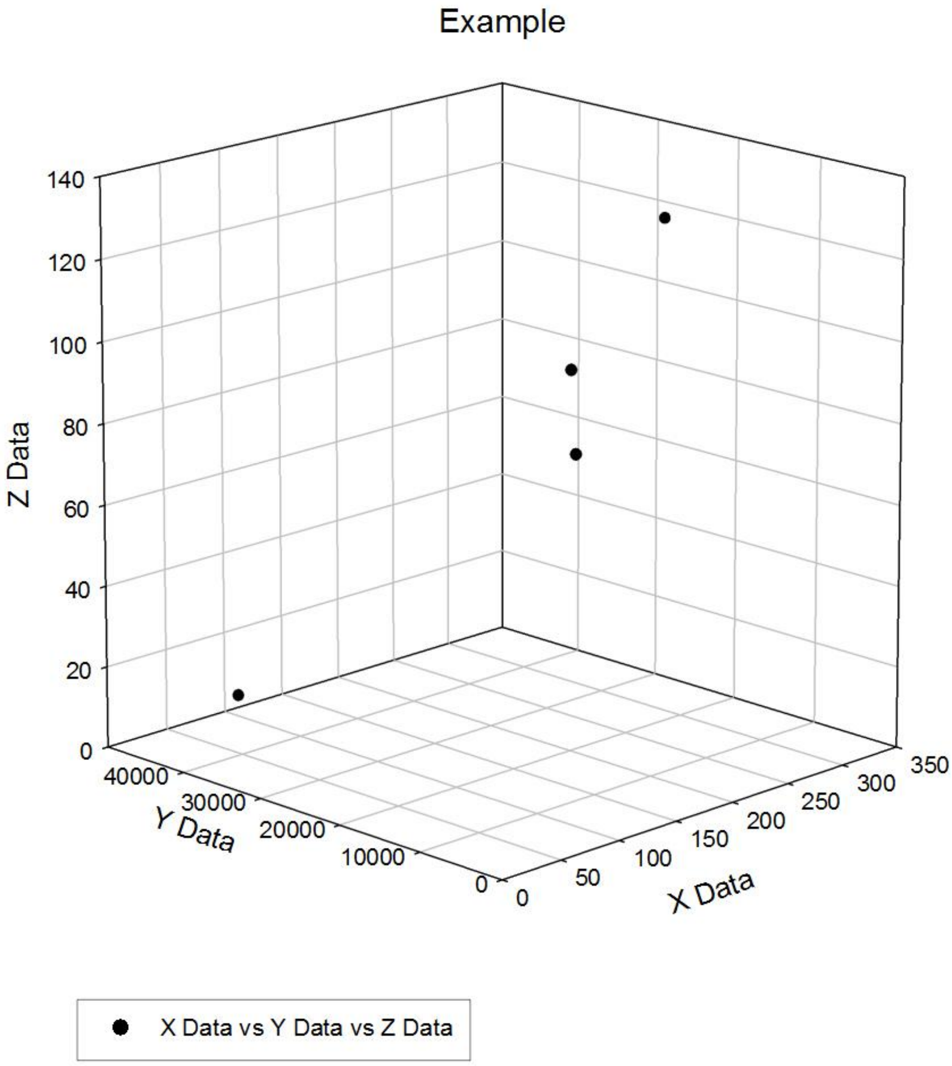

Figure 3.5 Graph representing correlation between cost and frequency.

In figure 3.5, the data in Y axis is being added into the 2-dimensional quadrant to create a 3-dimensional model. The 3-D model can create a more complex category system to classify items in the inventory. This increases from 4 categories 2-dimension quadrant matrix to 8 categories in a 3-dimension quadrant matrix.

Table 3.1 show the representation of 3-dimensional quadrant matrix in a table form. Each variable in the matrix are located on the top, bottom, and on the side of the matrix. The number in the matrix represent the category of the item.

Table 3.1 Table Representing 3-Dimensional Matrix

	Low Order Lead Time	High Order Lead Time	Low Order Lead Time	High Order Lead Time
High Malfunction Number	X	X	1	2
Low Malfunction Number	3	X	X	4
High Malfunction Number	5	6	X	X
Low Malfunction Number	X	7	8	X
	Low Accumulated Cost	High Accumulated Cost	High Accumulated Cost	Low Accumulated Cost

3.2 Analyze existing spare part service).

The current method company use to manage spare part is by ordering spare based on the historical data and estimation. For this project the spare parts order is approximately 3-5% of the total number of the equipment currently uses in schools and agencies currently use in the project. These spare-equipment are order 2 to 3 times a year, to ensure that there is enough spare part to be use in the project. Some parts are order in bulk at the beginning of the project, and some of them are order many time during the year. Some malfunction equipment such as switch, router, and UPS can be repair if broken. If the equipment is within the warranty, it can be repair and replace.

Table 3.2 Unit amount and unit price of the equipment in the project

Equipment	Switch	Router 892	Media Converter	UPS
Equipment Amount	1,200	3,000	3,000	3,000
Unit Price	40,000	22,000	3,000	2,000

Data table 3.2 show, the total unit amount of each type of equipment used in the project and the approximate unit price of these items. These data can be used to compare and calculate with other data to find ratio or, the cost of the product over a given period.

Table 3.3 Ticket Issue and Spare Part Inventory from the Beginning to the End of the Project 2013

	Switch	Router 892	Media Converter	UPS
Ticket Issue	52	338	84	96
Spare Part purchase 2014	11	80	100	100
Number of Spare Part Available	17	97	134	86
End of Year Stock 2014	7	65	68	51

Table 3.4 Ticket Issue and Spare Part Inventory from the Beginning to the End of the Project 2014

	Switch	Router 892	Media Converter	UPS
Ticket Issue	52	338	84	96
Spare Part purchase 2014	11	80	100	100
Number of Spare Part Available	17	97	134	86
End of Year Stock 2014	7	65	68	51

Table 3.5 Ticket Issue and Spare Part Inventory from the Beginning to the End of the Project 2015

	Switch	**Router 892**	**Media Converter**	**UPS**
Ticket Issue	56	325	82	121
Spare Part purchase 2015	7	35	100	115
Number of Spare Part Available	13	100	175	166
End of Year Stock 2015	6	54	93	50

Table 3.3 to 3.5, show data gathered from 2013 to 2015, each table show number of ticket issued for each item, spare part purchased, and spare parts in the inventory at the end of the year. These data can be compared and analyzed to find pattern between each year. Data such the inventory ratio could be calculated by dividing total ticket issues and spare part available.

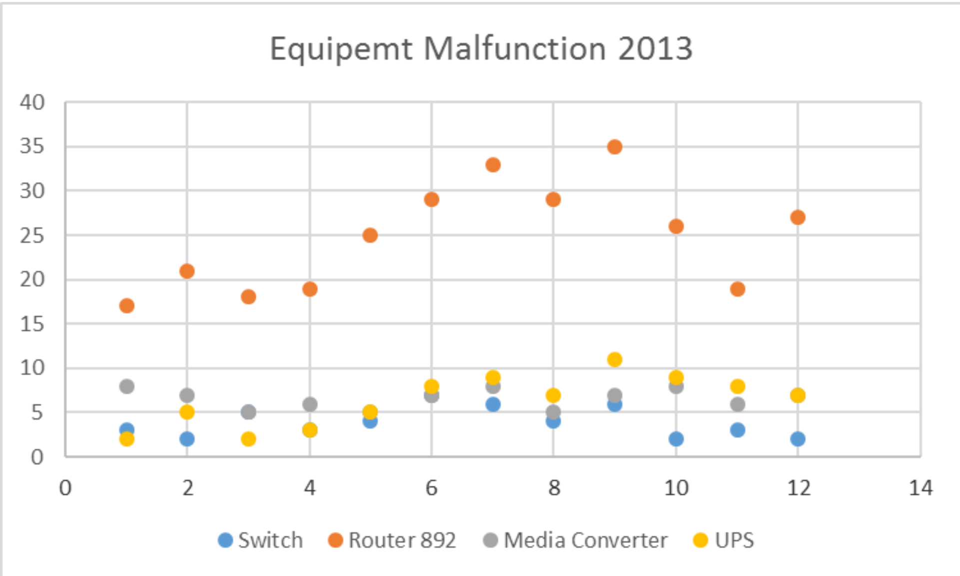

Figure 3.6 Number of times equipment malfunction in 2013.

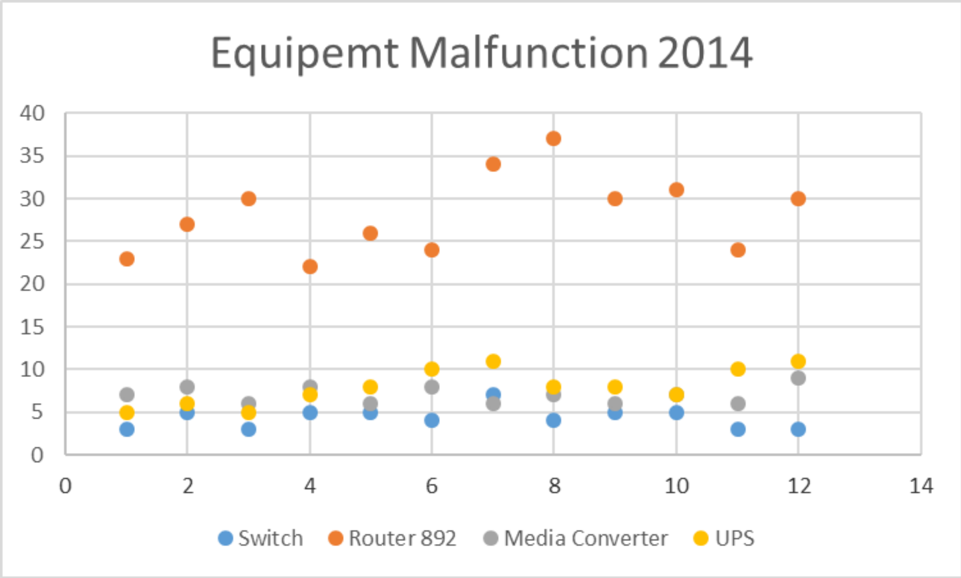

Figure 3.7 Number of times equipment malfunction in 2014.

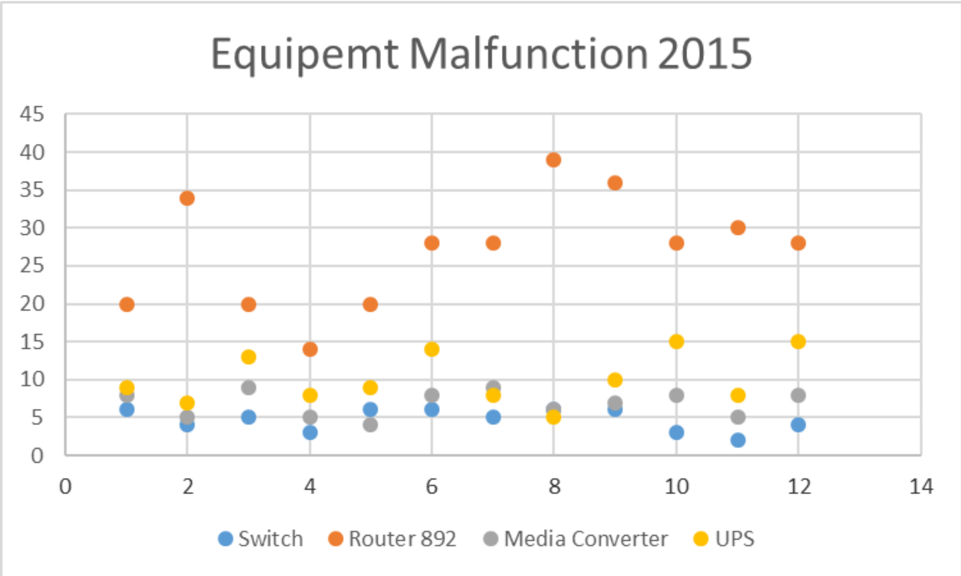

Figure 3.8 Number of times equipment malfunction in 2015.

To see the pattern of the failure rate of the equipment over 3 years the number of the ticket issue from equipment malfunction can be compare year by year. From table 3.6 to table 3.8, the plots of time equipment malfunction over 3 year, every month. When looking at the 3 graphs, a stand out pattern can be seen for router malfunction number. Every third quarter in every graph show higher rate of malfunction relative other quarter. For other item, there is no significant trend is visible on the graphs.

Table 3.6 Failure rate of the network equipment from 2013-2015

Year	Switch	Router 892	Media Converter	UPS
2013	3.92%	9.93%	2.63%	2.53%
2014	4.33%	11.27%	2.80%	3.20%
2015	4.67%	10.83%	2.73%	4.03%

Table 3.6 show the failure rate of the network equipment from 2013-2015. The data can be convert in the form of ratio, as it represents relationship of replacement equipment and total equipment in the project. This is done by dividing the number of ticket issue by total equipment. When compare these data year on year, a trend can be seen that over years failure rate have increase. Especially, for switch, UPS where the failure rate increase over 3 years. For product like router and media convertor, the failure rate spike up in 2014, but the rate drop slightly the year after. However, the data show that router failure rate is relatively high when compare with other type equipment. This suggest that it might be time to replace the router in this project.

Table 3.7 Lead Time to order and repairing lead time of Network equipment

	Switch	Router 892	Media Converter	UPS
Order Lead Time	30	30	14	7
Repair Lead Time	30	45	14	20

Lead Time in the table above show how long it take to order new spare part, and the long it take to repair the repairable spear-part. Equipment like media converter and UPS battery, are mostly non-repairable or difficult to repair. Once broken, these items are rarely reuse, as they are not very expensive a lot of them can be reorder easily. In addition, having excessive amount of inventory lead to higher space consuming, over warranty of the product, and opportunity costs. Therefore, it is no needed to have excess amount of inventory with low lead time.

3.3 Apply data to the method.

After needed data on the spare part inventory, failure incident, and other related data were gathered. The next step is to analyze these data by input these data spreadsheet in the format or the array base on the method mention in 3.1. The analyzed data, in 3.2 can also be present in the method format. The data can be present in the format as follow:

ABC When the report of unit cost and annual consumption is generated. Annual consumption value of each item can calculate according to the formula [8].

Table 3.8 The analyzed data of spare part inventory in 2013

Equipment	Switch	Router 892	Media Converter	UPS
Ticket Issue				
Cost per Item				
Annual Cost				
Cost Ratio (Cost)				
Inventory Ratio (Frequency)				

After the calculation, arrange annual consumption value each item in an array. Table above shown data of 2013 accumulated cost of each item in the spare part inventory, failure rate, number of spear-part purchase, and various ratios. The advantages of viewing easily in term of number and percentage, and a lot of number could be put into the table. However, data presented here is relative difficult to read and interpret or compare. With data of unit cost and annual consumption is generated. Annual consumption value of each item can be calculated according to the formula [7]

Annual consumption value = (Annual demand) x (item cost per unit) [7]

The relationship between annual consumption value and total consumption is use when doing the ABC analysis.

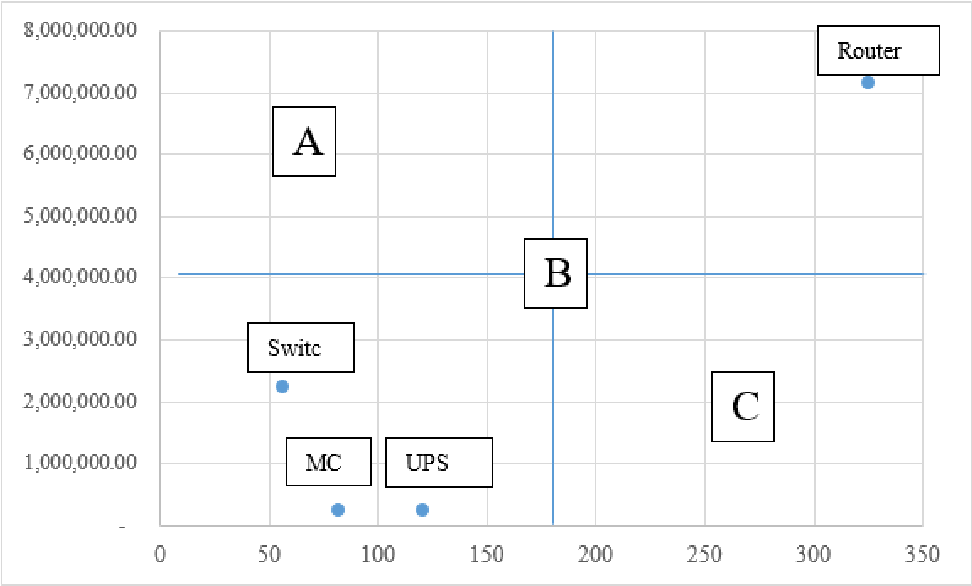

Figure 3.9 Accumulated Cost vs Equipment Malfunction.

From figure 3.9, ABC method is used to see the what category items inter spear-part inventory can be classify in. The result, show that 4 items in the inventory cannot be classified in any category. Because characteristic of the items does not match with ABC methodology.

Table 3.9 Replacement Ratio and Inventory Turnover Ratio for Each Item.

Equipment	Switch	Router 892	Media Converter	UPS
Total Units in this Project	1,200	3,000	3,000	3,000
Ticket Issue	47	298	79	76
Total Estimate Stock	21	150	133	63
Turn Over Ratio	2.238095238	1.986666667	0.593984962	1.206349
Replacement Ratio	3.92%	9.93%	2.63%	2.53%

Based on the data present in table 3.8 the spare part turnover rate can be calculated by dividing the number of item in the stock at the beginning of the project by the number of malfunction incident in that period. The turnover ratio show how fast spare parts are being move over a given period, in this case one year. The higher the turnover can be interpreted that equipment in the inventory move many times. This also reflect how the stock is be manage as existing spare part in the inventory can be utilize. It can also reflect on how that item can be repair after broken and be reuse without having to buy new spare part. On the other hand, item with low turnover rate is the result of the low movement the in the item. It could be that item is being over stock or that item could not be one broken. From figure 3.9, it can be analyses switch have the highest turnover rate, with its relatively low amount in stock, compare to other items. In contrast, Media converter has the lowest turnover rate with number of total number of spare part almost double the number of ticket issued.

For this project, the data is not suitable to be analyze in term of VED analysis. In every spare part item in the inventory are as equally important, because they all have the same SLA which is 48 hours. The impact of no having any of 4 items in the inventory when needed can be result in fine from the contractor.

To analyze the data in the XYZ method is also very difficult, from figure 3.5 to 3.7, these plotted graphs of the monthly ticket issued in each year is difficult to recognize in a specific pattern. The only pattern that can be perceive from the graph is the spike in ticket issues in third quarter of each year.

3.4 Select the suitable method

After examining method and models, analyzing existing spare part data, and applied the data to various method. Now it is time to find the model which best represent the network spare part management.

From analyzing different methods commonly uses for inventory management. It could be concluded that each method has its limitation in term of usage and applicability.

- ABC Analysis is simple to apply, but is very limited on how data that is not in the classification can be apply. It is also overlooking the highly critical parts with low consumption value, periodic updating and review is crucial.

- FSN can be used to monitor turn over, but should not be used to manage raw material inventory as raw material in production could be consider as consumption.

- VED is the most common in spare part management, but does not apply when every item in the inventory have the same SLA.
- XYZ is use to analyze when number of items can be varied every month, However, item lost or delay in shipment can influence the analysis [11].

From points, above, we can see that ABC and VED analysis are not appropriate with the existing information that we have on the characteristic of last-mile network spare part. FSN can be used to analyze the turnover of the spare part but it has it only offer one perspective on how item can be manage. XYZ analysis also has it limitation, as not every item in the inventory has demand pattern that can be used to analyze. In 3.1 a method has been created where data of variables can be plotted into quadrant matrix where items in the inventory can be classified to 4 categories. This method then later applied to a 3-diminsional quadrant matrix. The advantage of this method is that it increases variable, from 2 to 3 which create a complexity model. With this model, accumulated cost, repair lead time, and accumulated demand are the 3 variables that will be use to classified the network spare part inventory to classified items to 8 categories.

CHAPTER IV
RESULTS AND DISCUSSION

In this chapter, we will present the result of the 3-dimensional quadrant matrix model using 3 variables important in the spar-inventory. Then analysis the model in a break down format and discuss the result.

4.1 Create 3-Dimensonal Quadrant Matrix

Using SigmaPlot software version 13.0 to create a 3-dimensional scatter plot with input; number of items malfunction over, accumulated Cost over 3 years, and repair lead- time, shown in table 4.1

Table 4.1 Input data

Equipment	Accumulated Equipment Malfunction	Accumulated Cost	Repair Lead Time
Switch	155	6,200,000	30
Router 892	961	21,142,000	35
Media Converter	245	735,000	14
UPS	293	586,000	14

Figure 4.1 present a graph generated by Sigma Plot in a 3-dimensional format, with the 3 axes represent variables of the items in the inventory.

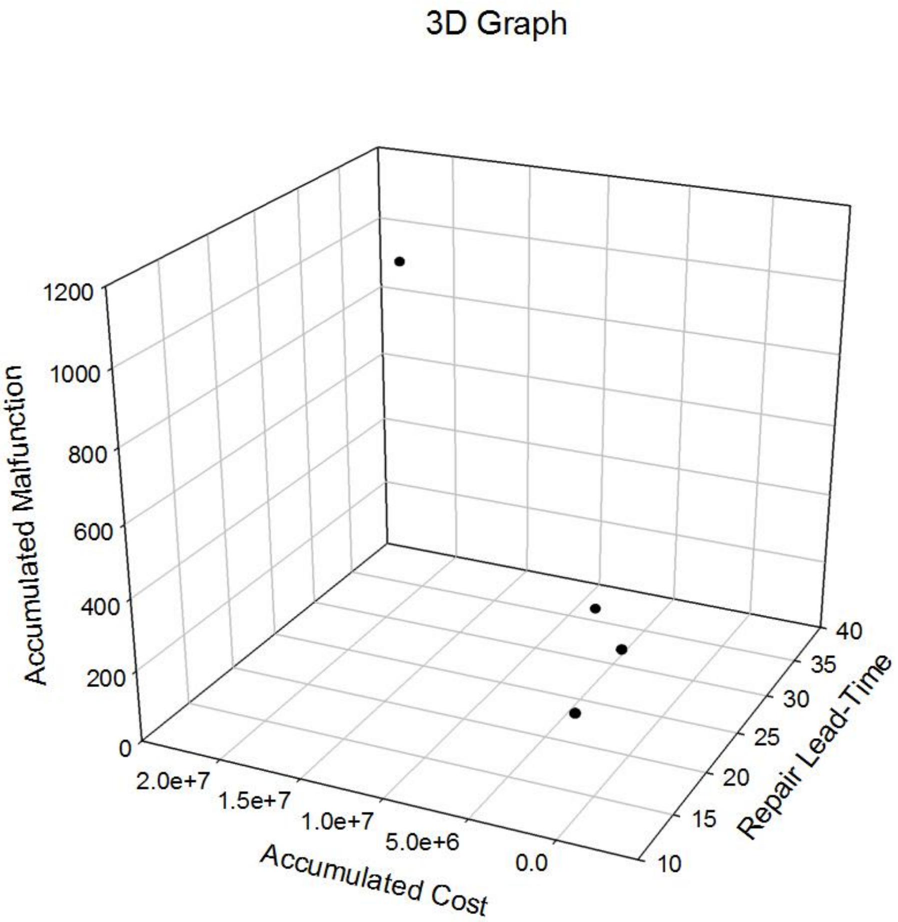

Figure 4.1 Accumulated Cost vs Purchase Lead Time vs Accumulated Demand.

4.2 Analyzes

Without being able to rotate or moving the perspective when viewing this graph. It is quite difficult to see each pint in the quadrant.

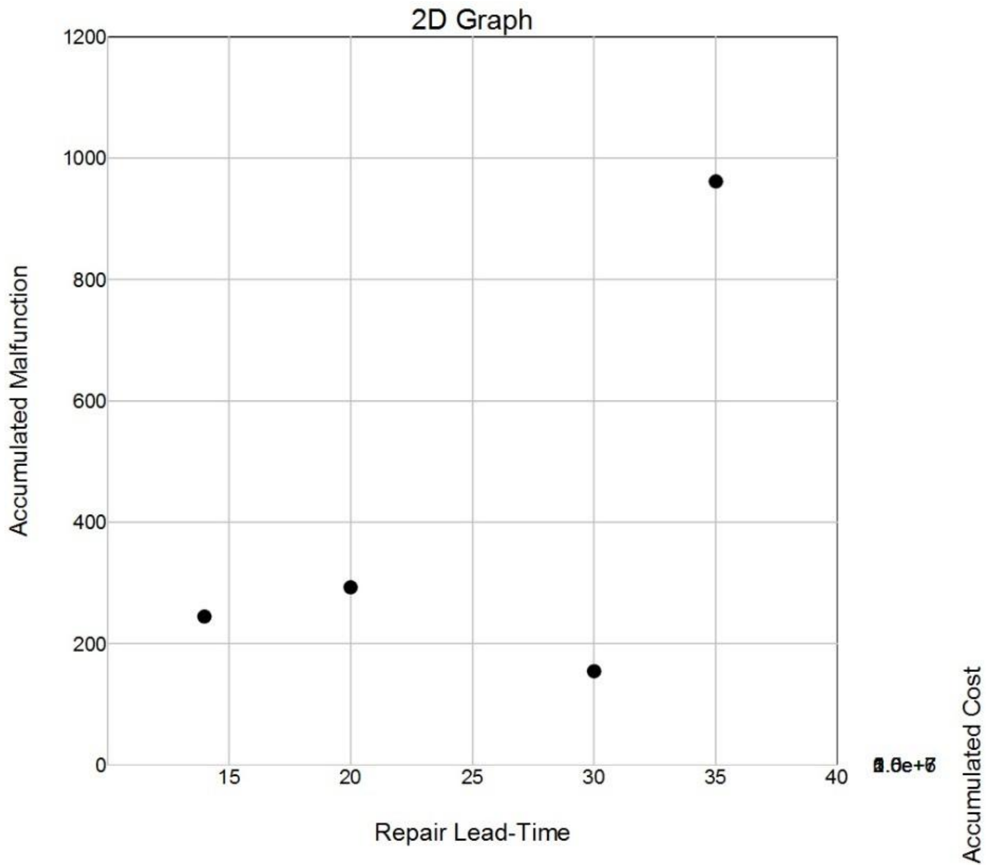

Figure 4.2 Number of Equipment Malfunction VS Repair Lead Time Quadrants.

In order make it easier to analyses, the 3-dimensional quadrant matrix can be simplified into the perspective of 2-dimensional quadrant matrix. In figure 22, Number of equipment malfunction and accumulated cost over three years are taken in to perspective. The plotted scatters fall into 3 quadrants in this matrix which are category 1, 2 and 3.

	Low Repair Lead Time	**High Repair Lead Time**
High Malfunction Number	-	Router
Low Malfunction Number	UPS, Media Converter	Switch

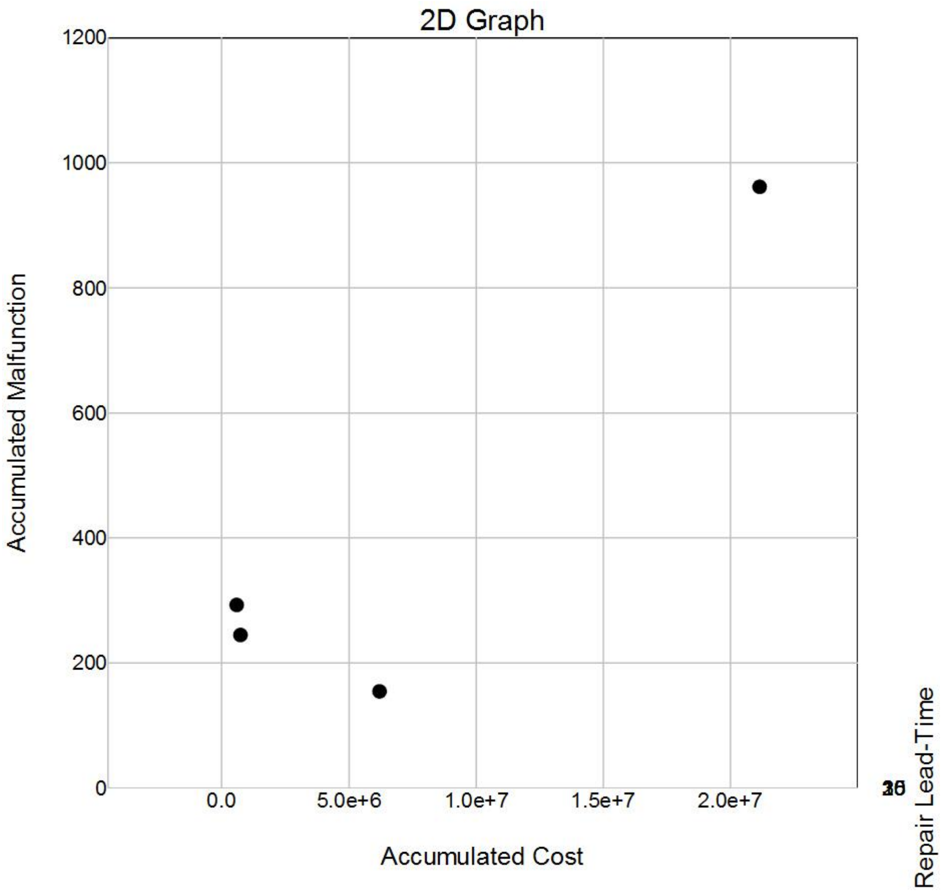

Figure 4.3 Number of Equipment Malfunction VS Accumulated Cost Quadrants.

Figure 4.3 shows another dimension in the matrix, comparing accumulated cost each item in the inventory with its accumulated malfunction over 3 years. The figure can be simplified to the table as follow:

	Low Accumulated Cost	**High Accumulated Cost**
High Accumulated Malfunction	-	Router
Low Accumulated Malfunction	UPS, Media Converter, Switch	-

Table 4.2 Accumulated Cost vs Purchase Lead Time vs Accumulated Demand in Table

	Low Repair Lead Time	**High Repair Lead Time**	**Low Repair Lead Time**	**High Repair Lead Time**
High Malfunction Number	X	-	-	-
Low Malfunction Number	UPS, Media Converter	X	X	Switch
High Malfunction Number	-	Router	X	X
Low Malfunction Number	-	-	-	X
	Low Accumulated Cost	High Accumulated Cost	High Accumulated Cost	Low Accumulated Cost

Table 4.2 is summarized of the 3-dimension scatter quadrant matrix into a table format. The result on the table, show that 4 items in the spare part inventory can be classified into 3 categories.

Table 4.3 Accumulated Cost vs Purchase Lead Time vs Accumulated Demand in Priority Matrix

	Low Repair Lead-Time	**High Repair Lead-Time**	**Low Repair Lead-Time**	**High Repair Lead-Time**
High Malfunction Number	X	X	5	5
Low Malfunction Number	-15	X	X	-5
High Malfunction Number	-5	15	X	X
Low Malfunction Number	X	5	-5	X
	Low Accumulated Cost	High Accumulated Cost	High Accumulated Cost	Low Accumulated Cost

To make the matrix easier to interpret, 4 colors is chosen to highlight the cell which represent character of item in the inventory. In table 4.2, characteristic of each cell in the matrix represent in color representing how much priority should be given to each category in the model:

- Green: Very Low priority
- Yellow: Low priority
- Orange: High priority
- Red: Very high priority

We can see that router fall into cell highlighted in red, this is because it has high accumulated cost, high accumulated malfunction number, and high lead time. This mean that router need to be given a very high priority in term of how this item need to be manage. On the opposite end items like UPS and media converter are in green category, which mean that all of them score low in all the 3 categories. So, for this type of item little attend is needed. For switch, in yellow, low priority should be given to this item as if has low accumulated cost, and low accumulated malfunction, but only high lead time.

4.3 Discussions

Result shown on the quadrants shown that items in the inventory can be categorized based characteristic. The model that we selected prove to be useful in categorize network spare part in the form of 3-dimensional quadrant matrix system. The model help to categorize spare part based on attributes that are important to spare part management.

Compare to the ABC analysis, the 3D quadrant matrix model allows items to be categorized to the suitable constrain in spare part management, which are cost, lead time, and failure rate. The model is flexible, as the variable can be change, new variable can use as substitute for the existing variable. Moreover, the model allows the spare part inventory to be manage specifically on each item. Because items under 3-dimensional quadrant matrix can be categorized into 8 specific characteristics. However, the variable represent in this paper might not be apply to other type of inventory.

4.4 Limitations

Even though, the over project is very large, we only look at the last-miles equipment in the project. This study does not look at spare part inventory of the distribution nodes, and backbone network. Thus, the equipment type in the spare part inventory are quitted limited. Therefore, the outcome representing in the characteristic are quite limited.

The data ticket issues and amount of the spare-inventory are taken form the ticket system and spare part database. The accuracy of the data depends on how accurate these data is being input into the system.

The model serve as a guideline of the characteristic of the item in the inventory. The policy on how each item should be manage depend on how the data is interpret.

CHAPTER V
CONCLUSION

In this paper, we establish a scientific literature about a suitable model for last-mile network spare part inventory management base on equipment characteristic. It shows how spare part inventory can be categorized based on cost, lead time, and malfunction rate. Because of the current spare management models are still limited on how data can be categorized. The 3-dimensional quadrant matrix model are flexibility and delicate. This method, allows items to be categorized to 8 categories.

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