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RISK BASED PREDICTION TECHNIQUE ON CRITICAL SPARE PARTS REQUIREMENT FOR PLANT PRODUCER

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ABSTRACT

The number of major losses and equipment breakdown due to unavailability of spare parts has posed challenges for planning and inventory control. Moreover this issue can lead to unproductive breakdown of the equipment with eventually give impact towards company's profit. Most of the inventory planner strengthen their inventory policies by maintaining high inventories of spare parts in which resulting irrelevant to the total cost of the asset investment. The inventory planner is considered risk neutral and willing to trade off between the lower profit gain for the protection against possible production losses. Nevertheless, the objectives of maintaining high inventories of spare parts often conflict from meeting the needs of risk averse inventory management. In view of this situation, the management of spare parts become critical issue in the company and it is suggested to quantify the potential impact in order to reduce risks.This paper describes the development of risk quantification technique using Spare Parts Probability Derivation Table for the plant inventory control. The table will provide the probabilities of four critical spare parts that has been identified by the maintenance planner. These probabilities can be used to quantify the risk for the spare part failure and later to produce optimization in terms of risk and finding the minimal inventory cost.

Keywords: inventory risk, inventory holding cost, monte carlo.

INTRODUCTION

A higher maintenance cost, unexpected failures, down time and loss of production associated with equipment failures can create disastrous problems in any process plant. In United States about $ 300 billion has been used for the purpose of plant maintenance and operation (Dhillion, 2002). Malaysia industry also is no exception to this issue where in construction industry alone, the management spent average RM40 million or 12% of the annual budget for the cost of maintenance (Heng et. al, 2009). In addition, Krishnasamy et. al (2005) has discovered that manufacturing company spent about 80% from its operation cost to address issue on equipment failures and injury to people. These issues actually have drawn response among various parties of business and industries to look into maintenance management seriously (Liyanage and Kumar, 2003).

Maintenance of production machinery incurred a lot of money worldwide. Machinery breakdown due to uncertainty equipment failure increase the cost of repair and production downtime. Thus, it is important to understand the maintenance function in manufacturing industry to ensure the operation is reliable (Udin & Othman, 2008). Nevertheless selecting the right method to address the issue of maintenance is quite crucial and sometime become the toughest part of the management decision (Tixier et. al, 2002). (Krishnasamy et. al, 2005) stated that the blend of different maintenance strategies will assist the company in increasing the equipment reliability and substantially can reduce the maintenance cost. For instance Krishnasamy et. al (2005) added that various maintenance techniques have been applied in oil-fired power plant to rise the operation readiness and cut the maintenance cost as most of the equipment is functioning within enormous operating condition. The failure of the said system can result calamitous for the people that depending on electricity during winter season.

Maintenance and inventory management are the two functions in the company that is interconnected to each other. On top of having a good maintenance practice, the reason of a greater attention for the company to keep its inventory is to ensure the maintenance can restore the equipment according to its intended function (Van Horenbeek et. al, 2013). For each spare part the number of the item is determined by the demand from the corrective action that has been conducted by the respective maintenance personnel. Usually the maintenance very much depends on the spare parts availability to restore the item in order to reduce the downtime failure and cost. On top of all issues that is related to maintenance risk, there is a need to install an appropriate inventory technique that can address the issue of maintenance (Adeyemi & Salami, 2010). For instance imbalance of inventory items can create a business failure. If a maintenance planner facing experiences of stock out of a critical inventory item, it could result a production shutdown. If an inventory item is not provided when the maintenance planner thinks it should be required, the inventory care taker need to source the material anywhere in which sometime will incur an additional cost to the company. In conclusion, effective inventory management can make a substantial contribution to a company's revenue and also increase its yield on the total assets. Being refers to as inventory management it is not just addressing the issues of maintenance availability, but it covers the management of the economics of stockholding. For many company, the ultimate goal inventory management is that every inventory expenses will be translated into financial balance sheet (Adayemi &Salami, 2010).

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According to Khan & Haddara (2004), a lot of methodologies have been created to commence an inventory risk analysis on an industrial plant. The ranges of the methodologies are coming from the aspect of qualitative to the vastly quantitative. However, the most difficult part of the whole process was to select the right methods to address the maintenance needs. By selecting the right technique the maintenance manager would be able to assist the company to increase the plant reliability and reduce the operating cost. Dhillion (2002), agreed that by eliminating certain risk in maintenance, the operating cost can be reduced of about 40-60%. On the other hand, materials and equipment's availability playing a significant role in maintenance strategy. According to Sullivan et. al (2010), inventory management has the largest impact towards maintenance productivity. Due to improper inventory management, resulting in stunted maintenance process and ultimately led to the issue of company opportunity loss. Nevertheless, questions have been raised on how to determine the optimal size of the inventory based on the risks inherent in the equipment. In view of that, there is growing concern to address the issue of inventory based on the potential risks posed by the plant.

RISK PREDICTION MODELING

Introduction of risk prediction modeling

The design of spare part inventory management system is very important to an organization that deals with thousand line items of spare part in their warehouse. It is aimed to determine the optimal level of inventory in order to reduce cost. Besides having various techniques on evaluating the optimal level of the inventory, it is good starting point to analyze the optimum inventory level by using risk (Ibrahim et. al, 2010). In particular some organizations are willing to pay extra costs in order to reduce the possible inventory risk faced by them. In other words, the degree of risk reduction is depending on the cost of providing extra security to the entire system. The amount of money spending is getting smaller as the degree of risk reduction become bigger. However, the optimum level between the risk reduction and customer willingness to pay will meet at the point of the lines is intersecting. This means the optimum level will be achieved when the cost of providing extra security equals to the customer willingness to pay of the risk reduction.

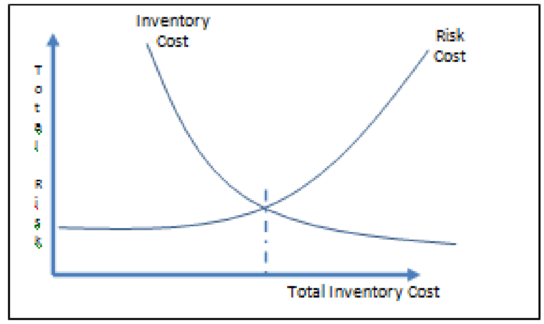

Figure-1. Optimum level between total risk and inventory cost.

Figure-1 exhibited that customer are willing to spend extra money in order to reduce risk. In other words, inventory management is a financial balance between stock-out costs and inventory costs. The more investment is needed for more stock and indirectly it will incur more stock depreciation. On the other hand, if no stock available or stock-outs, it will give a bad impact for the maintenance activity and possibility of interrupting the whole plant production process.

The risk prediction modeling is developed to address the inventory issues by developing a new method to quantify risks by predicting the level of inventory quantity from selected spare parts item in plant production. It focuses on the frequency of equipment breakdown in plant operation demand of the spare parts and number of the spare parts replacement during the plant maintenance works. Other challenges in plant maintenance such as raw material break down, logistic issues, power interruption, and financial problems may affect the operation of the company. However the study is only focuses on the issues of plant breakdown based on the historical data and inventory requirement for each of the situation of breakdown happened. The quantified risk method proposed in this study, will assist the urea producer to make a decision in supply chain strategy that provide optimal option of inventory cost within minimal risk. This section started by determining the critical item in plant maintenance work based on historical data provided by the maintenance planner of the organization. In this study maintenance planner is referring to the person that manage the maintenance and decide the inventory level in the organization. It describes the equipment failure history or breakdown and frequency of spare parts replacement from identified critical equipment.

Risk prediction framework

The uncertainty of spare parts requirement in the plant maintenance activity will cause disastrous as it may affect the plant operation. If the spare parts that are really required during the plant operation, does not exist or is not enough to cater the plant requirement, the operation need to be slowed down or in worst case scenario it has to stop the operation. The operation discontinue will create

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opportunity loss and effect the company financial performance. In contrast, if the company overestimates the number of spare part to be purchased and unable to quickly make use for the maintenance, it will result the company having problem in storing the spare part. With limited storage space, storing one expensive spare part creates an extra cost because sometimes the company cannot store as much of other spare part items. Eventually it will leave the company storing items that consumers no longer wanted and creating the habit of over purchasing. Without a proper planning of spare part requirement, it will cause the management to bear the cost of the holding cost. According to Pyke and Cohen (1994), it already becoming burning issues as approximately fifty per cent of a company in most industries was occupied with inventories assets.

In an attempt to minimize or avoid such losses, this research employs risk technique by quantifying the risk from the prediction of the optimal spare parts level. In this situation there are two main factors that can be focused on, which are the frequency of equipment breakdown and frequency of spare parts replacement. The level of the risk value will be depended on the formulation strategy from the number of spare parts required and the frequency of replacement. The framework for the risk and spare parts quantification is showed as below:

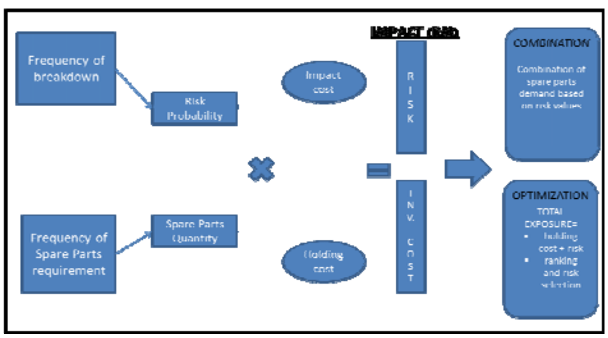

Figure-2. The framework of risk based technique for optimal spare parts inventory level.

In Figure-2, the issues of breakdown in plant operation is segregated based on quarterly time. This is due to the reason that the management will do the financial and asset review of every quarter of the operation. Thus it is quite relevant for the review of the maintenance and inventory status in quarterly basis. Based on this study,the model parameters refer to the frequency of plant breakdown and frequency of spare parts replacement. The spare part demand is refers to the level of stock that has been pre-determine by the plant operation based on the historical data and concessive judgment by the maintenance experts. While the frequency of spare parts replacement is the number of the spare parts that need to be replaced due to equipment break down and malfunction. In this study, a case study of spare parts inventory from urea plant producer was selected as the company is considered as sole manufacturer of urea plant producer in northern region of Malaysia. Historical data of the spare parts demand and replacement activity were collected from the year 2000 until 2014. The collected data is in the form of numerical and randomly distributed. The value of probability level of frequency breakdown is used to measure the level of probability in selecting the optimal number of spare parts demand. The probability level will be multiplied with the value of impact in order to get the risk value. On the other hand, the quantity of spare parts will the determine demand of the spare parts and will be multiplied with the holding cost to represent the total holding cost. In order to obtain the likelihood demand of the spare parts, the Monte Carlo Technique is used to verify the selected demand assumption.

Risk quantification technique

The topic of probabilistic risk has gained increasing attention in both academic research and in practice. The subject of risk become popular as it can be used in many ways. In defining risk (Wall, 2011) stated that risk is a set of scenario si, in which it has the probability, pi, and a consequences, xi. In further (Wall, 2011), describe the notion of the risk by denoting it as a triples values:

$$\{si,pi,xi\}$$

Where i=1,2..., N is employed to differentiate the scenarios.

In view of this situation, it is important to identify the value that allows the probability distribution can be quantified. In this research, the risk quantification is referred to the non-confidence level of the spare part inventory demand multiply the impact values to be borne by the company in the event of the no spare part available within the required time. By all means the risk value will be quantified in monetary value. The formulation below provides the expected risk level in monetary values.

$$Risk_{ncl} = (probability\ of\ nonconfidence\ level\ of\ inventory\ demand) \times Impact$$

This formulation will give the actual random values for the non-confidence level and will be calculated using Monte Carlo simulation. In order to calculate the non-confidence level inventory demand, the probability of the confidence level should be subtracted with the total probability which is equal to 1. For example, the percentage of the confidence level of inventory demand is 36% or 0.36. So the probability of the non-confidence level is equal 100% or 1 subtracted to 36% or 0.36 which is equal to 64% or 0.64. The following equation shows the formulation of the non-confidence level inventory demand.

$$Risk_{ncl} = (1 - probability\ of\ confidence\ level\ of\ inventory\ demand) \times Impact$$

Spare part probability derivation table (SPPDT)

Spare parts in manufacturing industries are categorized in different ways (Kennedy et. al, 2002). In

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particular, inventory of urea plant operation encompasses of raw materials, spare parts and finished products. In this research, besides the raw materials, spare parts play the most important role due to the reason that the maintenance will use to restore the plant based on its intended function. However some of these spare parts are important to the operation in a manufacturing plant and other parts do not have such a severe impact on the process. The obsolescence of the critical spare part may cause the plant operations disturbance. The critical maintenance analysis discloses that the probable failure of the spare parts availability would have a significant impact on the plant operation to run effectively. Criticalities of the spare parts are determined by considering the severity and impact to be borne by the company in the event of obsolescence of the spare parts in the inventory. In particular, critical spare parts selection will be based on situation of the unexpected failure experienced by the maintenance on certain critical equipment in the plant. Result of the failure may cause the plant shutdown and the situation will impact the plant losses of RM2, 688,000.00 per day. In order to quantify the inventory risk, with regard to the possible spare parts quantity, this study formulated Spare Parts Probability Distribution Table (SPPDT) for the list of the spare parts. The SPPDT is the method introduced to calculate the possible number of required spare parts by looking at demand and the frequency of replacement. The simulation process constructed using Monte Carlo Technique looking at the possible quantity of each of the spare parts that has been identified earlier. The probability of the spare parts will be calculated from the spare parts demand and frequency of replacement tabulation of outcomes of the resampling trails. Although the planner has established decision on the possible quantity of spare parts that need to be stored in the inventory, sometimes unexpected things happen in the plant that caused plant shutdown and equipment malfunction. Consequently, the value of probability distribution will be multiplied with the holding of the spare parts in order to present the risk value. By comparing the risk value with cost of providing the possible quantity of the spare parts, the excessive risk factor would increase the number of the spare parts kept in inventory and eventually raise the holding cost.

In view of this situation, the maintenance planner has decided to focus on five critical spare parts that will give the biggest implications towards the plant operation. There are natural gas compressor, process air compressor, sync gas compressor, ammonia (NH_3) refrigerator compressor and carbon dioxide (CO_2) compressor. Out of five compressors, 3 compressors have major implication towards the plant operation that will cause a total shutdown. The compressors are natural gas compressor, process air and CO_2 compressor. Meanwhile the other compressors will cause slow down to the plant operation. For this study the risk analysis will be focusing on the critical spare parts of the overall compressors in which contribute the highest implications on the reliability of the compressors. The spare parts are dry gas seal, bearing, rotor and minimum governor valve. In this research the demand history for each of the spare part is collected in order to measure the frequency of the replacement and gain understanding about the spare part reliability. Based on the investigation that has been carried out in the maintenance office, the demand history indicates that spare parts from the compressors need to be replaced due to unexpected failure caused by the listed spare parts. The goal of this research is to assess the risk exposure of each spare part and quantify the risk into monetary value. Before the risk quantification calculated, the frequency of spare parts replacement is obtained from the failure history of each spare part. As mention in the previous section, the number of replacement showed the failure frequency of the spare parts to perform its function and eventually cause the plant operation shutdown. The history of the spare parts demand is taken from the year 2000 until 2014. In order to calculate probability of spare part demand, the minimum and maximum number of spare part demand is identified. For example, the dry gas seal (DGS) for natural gas compressor experienced the demand from zero to 4 units of spare parts. This means that the maintenance had to restore the spare into the system and should have the spare in the inventory for 1 unit, 2 units, 3 units and 4 units. The minimum and maximum of spare part demand for every compressor is illustrated in the table below.

Table-1. The minimum and maximum demand for DGS from year 2000 until 2014.

Natural gas compressor
DGS :[0,1,2,3,4]

In the next probability derivation process, the frequency of replacement which was identified from the range of minimum and maximum demand values is calculated. For example, the replacement frequency of DGS for zero demand is 7 times, for demand of 1 unit is 4 times, 2 units 7 times, 3 units is 1 time and 4 units 1 time. The illustration for each frequency of replacement is tabulated below.

Table-2. The replacement frequency of the spare parts for natural gas compressor.

NATURAL gas compressor		
Spare part	**Demand**	**Frequency of replacement (Times/ Year)**
DGS	[0]	7
	[1]	4
	[2]	7
	[3]	1
	[4]	1

Then, in order to calculate individual probability of each of the spare parts the Monte Carlo simulation is use to illustrate it. According to Heizer and Render (2001),

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Lawrence and Pasternack (2001), Schmitt and Singh (2009), Jensen and Bard (2003) Monte Carlo simulation will do the mapping on the random number and match the random number with simulated events. Basically the simulated events are calculated randomly and link the explanation of the theoretical probabilities resulting from the acquired experiences. In this research, probabilities of individual spare pare is perform by calculating the frequency of every spare parts replacement occurring throughout the years in which from year 2000 until 2014. Consequently after getting the probabilities, cumulative probabilities is perform in order to get the random number intervals for each of the spare parts. The table below shows the probabilities and cumulative probabilities of the DGS.

Table-3. Probabilities and cumulative probabilities for DGS.

Spare part	Demand	Frequency of replacement	Probability	Cumulative probabilities
DGS	[0]	7	0.350	0.350
	[1]	4	0.200	0.550
	[2]	7	0.350	0.900
	[3]	1	0.050	0.950
	[4]	1	0.050	1.000

After getting the cumulative probabilities for the DGS, Monte Carlo is used to generate the random numbers between zeroes to one based cumulative probabilities distribution. This cumulative parameter will then use the Monte Carlo technique by employing replication of 1,000 in order to choose the best possible number of demand at which the probability is distributed. For each the demand allocation the probability set can be stated as:

$$P\{0\} + P\{1\} + P\{2\} + P\{3\} + P\{4\} = 1$$

The illustration of the cumulative probabilities and probabilities distribution show in the below table.

Table-4. Probability distribution based on 1000 Iterations.

Demand	Frequency of replacement	Probab ility	Cumulative probabilities	Probability distributio n (i=1000)
[0]	7	0.350	0.350	360
[1]	4	0.200	0.550	190
[2]	7	0.350	0.900	355
[3]	1	0.050	0.950	50
[4]	1	0.050	1.000	45

The calculation shows at which point of demand the probability is distributed. The selection of the probability distribution from an interval cumulative probability defines the probability that the confidence level is produced. The choice of the confidence level is calculated by transforming the value of the probability distribution into percentage. These levels relate to percentages of the area of the normal distribution curve. For example of the DGS, the confidence level 19% for the demand of [1] will determine by probability distribution of 190 divide by 1000. The following formulation gives the confidence level in percentage value.

$$\sum_{i=1}^{100} = \left(\frac{i}{i}\right) x\ 100$$

Table-5. Percentage of DGS demand confidence level.

Demand	Probability distribution (i=1000)	Percentage of confidence level
[0]	360	36.0%
[1]	190	55.0%
[2]	355	90.5%
[3]	50	95.5%
[4]	45	100%

Table-6. The Confidence level and the risk value of the DGS.

Spare part	Demand	Probability distribution (i=1000)	Percentage of confidence level	Percentage of Non-confidence Level
DGS	[0]	360	36.0%	64%
	[1]	190	55.0%	45%
	[2]	355	90.5%	9.5%
	[3]	50	95.5%	4.5%
	[4]	45	100%	0

Once the confidence level of the inventory demand is defined, it will be multiplied by the value of the impact in monetary value.

The impact values

The impact values from the above equation will be calculated only from one condition which is the impact from the failure of the spare parts to perform its required function. The failure to perform its function may result the compressor malfunction and consequently it will cause the plant to stop operation. Eventually it will cause production loss to the planT. Based on the syndication conducted with the production planner, the plant has the ability to produce 2100MT of urea per day. The current market price for urea granular is approximately USD400.00 per tan. By multiplying the value, total loss of the operation due to unscheduled failure is RM2, 688,000.00 (conversion of USD1=RM3.2). Thus the impact will depend on unavailability of the specified number of spare parts. If the spare part unavailable for 1 unit, thus the impact will be 1 unit of unavailable spare part per day multiple by the total loss of the operation.

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Table-7. Total impact for each spare part.

Demand	Unavailability of spare per day	Number of failure	Total Impact (RM)
[0]	1 day x 0 s/part	0	0
[1]	1 day x 1 s/part	1	2,688,000.00
[2]	1 day x 2 s/part	2	5,376,000.00
[3]	1 day x 3 s/part	3	8,064,000.00
[4]	1 day x 4 s/part	4	10,752,000.00

On the other hand, the cost of procuring the maintenance service is depends on the items severity. The cost is calculated based on the average of maintenance service paid to the particular contractor from the date of the spare parts installed inside the plant. Nevertheless in this study, as the maintenance cost is varies from one service to another, the plant maintenance planner has decided to only incorporate the impact of the production loss in the calculation. This is to avoid the disparity of maintenance cost among the difference spare part. Thus, based on the previous stated formulation, the impact will be multipled with the pprobability percentage of non-convidence level of spare part requirement.

Table-8. Total risk of the spare parts

Spare Part	Demand	Probability Distribution (i=1000)	Percentage of Non-Confidence Level	Total Impact (RM)	Total Risk (RM)
DGS	[0]	360	64%	0	0
	[1]	190	45%	2,688,000	1,209,600
	[2]	355	9.5%	5,376,000	510,720
	[3]	50	4.5%	8,064,000	362,880
	[4]	45	0%	10,752,000	0

Calculation of inventory cost

The inventory cost for the spare parts will be calculated based on the required number of spare parts that are obtained from the simulation using Monte Carlo. The quantity of the spare parts will be multiplied with the fixed cost of each of the spare parts. Then it also will be added with other holding cost such as storage cost, manpower cost, insurance cost and purchasing cost. In this study the total of inventory cost showed that the cost that the inventory has to bear if the case that the spare is not utilized by the maintenance within one year period. The holding cost is a cost that has been designated of RM5,000.00 for the period of one year with regard to all costs incurred by inventory management. If the spare parts still remain unused, there will additional cost of depreciation that will be added on top of the total inventory cost.

Inventory Cost$_{INVC}$ = Spare Part Fixed Cost$_{SPFC}$ + Holding Cost$_{HC}$

Table-9. The total inventory cost.

NATURAL GAS COMPRESSOR				Holding Cost	Total Inventory Cost
Spare Part	Demand	Cost per unit (RM)	Fixed Cost (RM)		
DGS	[0]	50,000	0	0	0
	[1]		50,000	5,000	55,000
	[2]		100,000	5,000	105,000
	[3]		150,000	5,000	155,000
	[4]		200,000	5,000	205,000

Spare parts risk total exposure

The spare parts total risk exposure can be defined as the total risk that will be borne by the company if the case they used specific options the spare parts quantity selection. The calculation of the spare parts risk total exposure is:

Risk total exposure$_{rte}$ = Total Risk$_{ncl}$ + Total Inventory Cost$_{TIC}$

Table-10. The total exposure for the spare requirement

Demand	Total Risk (RM)	Total Inventory Cost (RM)	Total Exposure (RM)
[0]	0	0	0
[1]	1,209,600	55,000	1,264,600
[2]	510,720	105,000	615,720
[3]	362,880	155,000	517,880
[4]	0	205,000	250,000

Results from the calculation above will provide information about the risk on the spare parts quantity option. The amount of total exposure for each spare part are different from each other. In this case the inventory planner can choose whether to keep three units with a total exposure of RM 517,880.00 or choose to keep four units of spare part as the total exposure is only at RM 250,000.00. With having more spare parts it will help the maintenance to reduce loss of operation with regard of no spare parts as the total exposure to keep more spare parts are still low. The graph also showed the comparison of total exposure of spare spart and at which point that the requirement of spare spare is required.

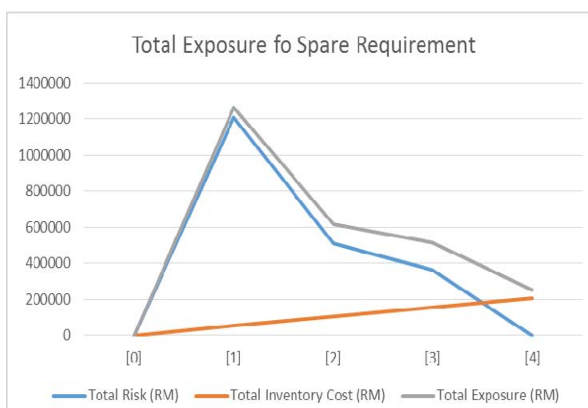

Figure-3. Comparison of spare requirement, total exposure, total risk and inventory cost.

CONCLUSIONS

The research presents a technique for designing optimum level of spare parts quantity by looking at the likelihood of inventory risk and inventory cost towards the maintenance performance. The technique contributes as principle guidelines for the maintenance planner to plan their inventory spare parts for maintenance activity. In order to achieve this, the technique will quantify the risk into monetary value which at the end of the day the maintenance planner would be able to make a better decision in identifying the optimum quantity of the spare parts. On the other hand, it also assist the inventory planner to plan the stockholding and design the inventory management in more effective way by looking at the perspective of risk. Thus it will ensure that the dependability of equipment is increased and the cost of inventory will be minimized. Indirectly, the technique will contribute to the performance of the plant operation.

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