A Risk-Based Technique Based On Spare Parts Quantity and Cost for Optimizing Inventory Level In Plant Maintenance

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Abstract

The purpose of this study is to make an improvement for the existing decision making through the development of risk based technique based on spare parts quantity level and cost to optimize the inventory level cost in plant maintenance. An investigation of equipment reliability and the need for the required number of spare parts in the production plant of PETRONAS has been conducted. By using the inventory spare parts database, the proposed technique should be able to demonstrate the developed technique and indirectly assist the company to improve their current maintenance and inventory management. This technique emerged due to awareness of importance on financial impact in managing plant operation. The risk based technique acknowledged the weaknesses and strengths of managing inventory of plant operation, and has great potential in improving decision making effectiveness. The empirical results and findings from this study are helpful to the inventory planner in the negotiation process of spare part inventory quantity determination with the plant maintenance as it provides information on the significant impact of inventory excess and shortage on the organization's financial risk. This work provides an original and significant contribution to the field of inventory management, risk quantification and optimization.

Keywords: Spare part, Inventory Cost, Spare Part Probability Breakdown, Risk Based Technique and Optimization.

Introduction

Maintenance of production machinery incurred a lot of money worldwide. Machinery breakdown due to uncertainty spare parts failure increase the cost of repair and production downtime. Thus, it is important to understand the maintenance function in order to ensure the operation is reliable

(Ghodrati & Kumar, 2005) . Researchers believe that the blend of different strategies will assist the company in increasing the equipment reliability and substantially can reduce the maintenance cost (Dekker ", Kleijn, & De Rooij, 1998; Krishnasamy, Khan, & Haddara, 2005; M. G. Sharma & Kashi N. Singh, 2014). However, to date only few researches that have been carried out emphasize on the integration of financial consequences and spare parts inventory requirement in plant operation (Hassan, Khan, & Hasan, 2012).

According to (Eckert, 2007), spare parts inventory management has the largest impact towards maintenance productivity. The improper inventory management decision making, resulting in stunted maintenance process and ultimately led to the issue of company opportunity loss. Furthermore, the adoption of a precise demand forecasting technique will make spare parts inventory manage more effective. In view of that, there is growing concern to address the issue of spare parts inventory based on the potential risks posed by the plant (Hagmark & Pernu, 2006).

All the mentioned technique has been successfully implemented in respective domain using a reliable forecasting technique and basis of forecasting. However, despite of its capability, little attention has been directed to consider the risk of spare parts left-over or excess as the main criteria in the existing technique (Zhu, 2015). Moreover, there is also less emphasize in integrating the optimal inventory size and cost with the potential risk in plant operation. Thus, this has motivated the study to improve the decision-making technique in determining optimal spare parts inventory quantity level and cost required by the plant maintenance.

Maintenance and inventory management are the two functions in the plant operation 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, Pintelon, & Muchiri, 2010). Normally, the quantity of spare part is determined based on the corrective action that has been conducted by the respective maintenance personnel. Nevertheless, most of the time the plant maintenance keeps increasing the spare parts inventory, just to address the short terms solution of maintenance (Adeyemi & Salami, 2010).

The question of how many spare parts to be stocked has been addressed by numerous researchers and has originated a wide variety of models (Kennedy, Wayne Patterson, & Fredendall, 2002). However, the adoption level of practices related to spare parts inventory is still scarce without concerning spare parts forecasting strategy (Hassan et al., 2012). An effective spare parts inventory management can make a substantial contribution to a company's revenue and also increase its yield on the total assets (Adeyemi & Salami, 2010). Hence, this has motivated this study to identify the needs of optimizing spare parts inventory with relation to the quantity level and cost in plant maintenance.

Literature Review
Spare Part Inventory Management
Spare parts Inventory Management plays an important role to achieve the desired state of plant availability. Since most of the industries nowadays are going towards for sophisticated technology and capital intensive, the breakdown of the machineries and equipment ridiculously expensive. In pant maintenance, the spare parts inventory management always exposed to high requirement of

demand and high risk of obsolescence. The three elements that contribute towards an effective spare parts management are maintenance inventories, spare maintenance policies and parts demand forecasting (Vaziri, 2014).

The spare parts cannot be predicted accurately on when the time of the breakdown and how many spare parts are required. Most of the times, the original equipment manufacturer is the one that need to provide the spare parts. Thirdly, the number and variety of spare parts are too large making the close control more and more tedious. In view of this situation, (A. Sharma, Garg, & Agarwal, 2012) adopting a real framework by incorporating the demand uncertainty and the financial implications in plant maintenance.

Spare Part Demand Forecasting Technique

Spare parts are known to be related to uncertain demand and that nature of demand pattern required forecasting and stock control in order to achieve the optimum stock level (Lengu, Syntetos, & Babai, 2014). In addition, (Willemain, Smart, & Schwarz, 2004) and (Regattieri, Gamberi, Gamberini, & Manzini, 2005) also use forecasting methods for the forecasting of uncertain demand in spare parts management Most of the time the forecasting of uncertain demand was heavily used in production and supply chain planning and the issues of demand have implication beyond the inventory control. Therefore, (Cavalieri, Garetti, Macchi, & Pinto, 2008) provided steps on the management process that can be organized accordingly such as identification of spare parts through part coding and classification, forecasting of spare parts requirements based on demand volume and pattern identification and development of the stock management system, with the formulation of the inventory control policies and systems, implementation in a computerized maintenance management system, for spare parts information processing and inventory control systems operation and policy testing for continuous performance improvement.

Risk Based Approach in Plant Maintenance

Three aspects are identified as important when analyzing the risk: the action or the sources causing the risk, the outcomes from the risk, and the impact measurement to adverse or mitigate outcomes. The missing point in all the spare parts inventory management literature is the comprehensive integration between the risk of spare part shortage and excess to the plant maintenance. Forecasting of spare part demand is the most difficult task, but the demand issues like failure of the equipment associated with unavailability of spare part and financial consideration. Hence, a more precise demand forecasting technique that emphasized on monetary risk is essential for successful and effective inventory management.

Methodology

Proposed Method of Optimization

To minimise the risk level in plant maintenance, the inventory planner can choose to increase the spare part inventory level. However, this strategy will incur a high cost. On the other hand, the inventory planner can also decrease the inventory cost by reducing the number of spare parts ordered. However, this will expose the plant operations to a higher risk in plant maintenance. At one time, the plant maintenance invested more money in securing plant operations, but it still exposed the plant operations to a finite level of risk.

The potential loss equation model that affects the above situation will be used in the optimisation process. This optimisation concept implies a combination of *total spare part risk* and *total inventory cost*, which will give a minimum *potential loss* value:

Total Potential Loss = Total Spare Parts Risk + Total Inv. Cost

Mathematical Formulation

The minimisation of potential loss will indicate the optimised value of the spare part inventory in plant maintenance. The objective function is given below:

Objective Function

Min{Total Potential Loss}

=*min*{Total Spare Parts Risk + Total Inventory Cost}

$$=min\{ \sum_1^j \sum_1^k (\Pr(j,k)) \times (SP_{shortage\_Impact} \times j + SP_{excess\_Impact} \times j)) + \sum_{SP=1}^n (price \times SP)\}$$

The objective function of this formulation is to optimise the spare part quantity by optimising the cost of spare parts and risk with different ranges of spare price for a given possible spare part combination.

Algorithm Selection

Genetic Algorithm (GA) has been used to identify the optimal level of spare parts based on the identified risk. GA is a randomised search methodology with roots in the natural selection process and use the crossover and mutation to acquire a generation of new solutions. Radhakrishnan and Prasad (2009) used GA to study the inventory optimal level based on the production and the requirements of the distribution centre.

Optimization Programme

This program examined the inventory spare part combination portfolio based on the spare part risk and inventory cost in meeting the plant maintenance requirements. It attempts to find the lowest *TPL* while ensuring that the option chosen are valid combination of spare part inventory level. This program developed all possible combinations of spare part inventory options from spare part quantity demands and breakdown history. The optimisation program is divided into two sections which are the GA Main Program and the Fitness Function Evaluation Program.

The GA Main Program is the control program that determined the program decisions and generated a set of spare part combination options population from the processes of mutation and crossover. The Fitness Function Evaluation Program subroutines then determined the Fitness Function values of the possible total potential loss from the plant maintenance and input data given. The process is generally described as follows:

Step 1: The combinations of spare part possible option (i.e. chromosome) are generated as initial population by the GA Main Program from spare part breakdown minimum and maximum as well as number of spare parts. Each combination consists of different combination of spare part quantity level according to the minimum and maximum breakdown of the spare part.

Step 2: New generation is set from the initial population by selecting 'n' number of chromosomes from the initial population.

Step 3: Cost of spare part inventory for each selected chromosome is calculated. This cost of spare part inventory later will be added up with spare part risk to give Total Exposure for each chromosome in the selected generation.

Step 4: The Spare Part Probability Breakdown Table for each of chromosome from selected generation is developed. The probabilities of all possible breakdown of the spare part are calculated from the history of breakdown.

Step 5: Spare part shortage and excess impact for every possible spare part shortage and excess is calculated.

Step 6: Risk of spare part for chromosome is calculated and added with cost of inventory to give the total potential (i.e.: fitness function value) for chromosome.

Step 7: The new generation chromosome is combining with the parent and all chromosomes are rank from minimum to maximum of *TPL*. The best *K* chromosome is selected. If the last generation/ iteration is not reached, a new parent will be created.

Step 8: Next, the children are created using the crossover and mutation process from the created parent. The closest possible chromosome is selected from the parent population if there is no the same chromosome of the child. The selected chromosome from the parent is deleted to ensure no repetition.

Step 9: Repeat Step 8 until last generation has been evaluated.

Findings

Test System and Spare Parts Inventory Data

Before the analysis begin, a generic test system that was developed using the mathematical model and forecasting methods for comparison purposes are identified. To achieve the best combination of spare parts inventory level for the plant maintenance, four different types of scenarios are tested accordingly. Subsequently, the best combination of the developed scenario will be compared against the optimization technique to gain the best possible combination. Thus, the selected scenario includes the last period demand, moving average, weighted moving average and exponential smoothing for the possible combination will be calculated using the risk based technique.

Scenario One

The possible combination for scenario one is identified as [0 0 3 1 0 3 1]. The value from the combination will be compared against the historical data of the spare parts breakdown. Subsequently, the probability of breakdown for each spare part will be calculated by dividing the possible breakdown with the number of observations.

After comparing the possible combination with the breakdown historical data, the frequency of breakdown is determined accordingly. Based on the developed frequency of breakdown, the probability of the spare parts breakdown is mapped accordingly.

Scenario Two

The possible combination for scenario two is identified as [1 1 3 2 1 2 1]. After comparing the possible combination with the breakdown historical data, the frequency of breakdown is determined accordingly.

Scenario Three

The possible combination for scenario three is identified as [2 2 4 3 1 3 1].

Scenario Four

The possible combination for scenario four is identified as [1 1 4 2 1 3 1].

The results have shown that the possible combinations using the identified forecasting technique resulting a lower point of probability breakdown as compared to no breakdown events. So, it can be concluded that the plant has less issue of spare parts shortage for more than four units of spare parts. Nevertheless, the distribution of the probability is quite high with breakdown of spare part between two to three units of spare parts.

Spare Parts Shortage and Excess Risk

Risk of spare parts shortage and excess is calculated by multiplying the probability of certain level of shortage with the impacts of that scenarios.

Shortage risk for every scenario of mentioned before. From this figure, scenario one which is using the [1 1 3 2 1 2 1] for the spare parts possible combination has the highest shortage risk resulting RM 21,280, 970.00. Meanwhile, scenario three which is using [2 2 4 3 1 3 1] possible combination has the least shortage risk which is RM 9,994, 010.00. However, in this calculation, scenario two and scenario four has given small differences in terms of the shortage risk value. Thus, it can be concluded, the possible combination of spare parts using the weighted moving average forecasting technique, will give highest value in terms of spare shortage risk for the plant maintenance.

From the possible combination perspective, scenario three possible combination which is [2 2 4 3 1 3 1] and scenario four possible combination [1 1 4 2 1 3 1] has differences for spare parts in terms of the quantity level. The spare parts level for scenario three is increased for one unit each of every spare part. Although the plant maintenance increase quantity level of the spare parts for scenario three as compared to scenario four, it can be concluded that the risk for the spare parts shortage and excess is still small.

Simulation Cases

First, the plant operating systems comprises of an Ammonia Plant, Methanol Plant, Urea Plant, Urea Formaldehyde (UF) and bagging facilities plant that is well integrated to perform its the ammonia production process consist of five critical equipment's which are Natural Gas Compressor, Syn Gas Compressor, CO2 Compressor, Process Air Compressor and Ammonia Refrigerator Compressor. In the case of the spare parts failure, two compressors which are Natural Gas (NG) Compressor and Syn Gas (SG) Compressor have major implication towards the plant operation that will lead to plant total shutdown. The NG compressor is the equipment that help the transportation of natural gas from the initial location to other operation system. Consequently, the unavailability of these equipment will lead to operational problem of the system and incur potential loss if the failure happens.

Result for Optimization (Optimum Combination)

In this combination, the cost of inventory is identified at RM17,650,000.00. While the total risk cost is identified at RM17,071,884.00. By adding the value of the risk and the total inventory cost the potential loss that will be gained by the plant maintenance is at RM34,721,884.00. Optimization technique provide the best possible combination with the lowest potential loss of RM34,721,884.00. Meanwhile the last period demand has showed the lowest in terms of inventory cost but giving the highest risk value in plant maintenance which is at RM21,485,312.00.

Spare parts that shows no changes in terms of quantity level although the potential loss, total risk and total cost having a slight difference in terms of cost value. In terms of quantity level, where for

best combination only require one unit of spare part. While the second best required to have two units of spare parts. In comparison, other spare part is reduced for one unit and the reduction has increased the value of total risk from RM17,071,884.00 to RM18,413,804.00. In directly, it increased the potential loss up to RM34,763,804.00.

The shortage an excess risk for the spare parts ten best combination is expected to increase exponentially as the excess risk increased. Similarly, the shortage and excess risk for every possible combination also increase accordingly. This happen because as the number of possible combination for shortage increase, the combinations for possible spare parts excess are increase at exponential rate. For instance, in possible combination three, the value of risk, is considered the highest value for shortage and excess but the inventory cost is identified the lowest value which is RM16,350,000.00. The total risk has negative relationship with the total cost. The combination eight in this figure has shown the biggest gap between the total risk and total inventory cost which is at RM7,954,412.00. While the smallest gap is identified at combination one which is RM578,116.00. In conclusion, the lower inventory cost the plant maintenance spent, the higher risk of the plant in getting the plant loss risk. While the higher maintenance plant spent for the inventory, the lower risk of the plant.
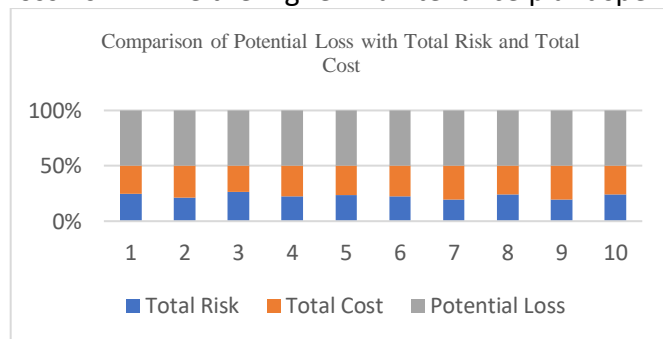

Figure 4.1
Comparison of Potential Loss with Total Risk and Total Inventory Cost

In Figure 4.1, combination one and ten have the best balance between total risk and total spare parts inventory cost which is the total inventory cost representing 51% from the total potential loss value while the total risk identified as 49% of the value. While combination three and eight having the same balance between total inventory cost of 47% and total risk of 53%. The combination number seven and nine is the less balance among the best ten of possible combination. The total inventory cost representing 61% which is higher than the total risk of 39%.

Sensitivity Analysis
Spare parts total price decreases 10%
The biggest gap between the total cost and the total risk can be seen in combination number one, with total of RM6,428,547, while in combination number six the impact cost is higher than the total spare part cost for RM283,607.09.

Spare parts price decreases 30%
The biggest gap between the total cost and the total risk can be seen in combination number four, with total of RM12,856,015.00, while combination number five and six is having the same potential loss value and considered to be to lowest gap of RM5,978,607.00.

Spare parts total price increase 10%

The biggest gap between the total cost and the total risk can be seen in combination number nine, with total of RM3,953,433.00 while combination number eight considered to be to lowest gap of RM2,519,873.00.

Spare parts total price increase 30%

Out of ten combinations, only one combination showed inventory cost higher than the risk. While the rest of the combinations showed that the total risk is higher than the inventory cost. The biggest gap in terms of higher risk was showed in combination ten of RM1,140,521.00. While the lowest difference was showed in combination one of RM271,949.00.

Extreme Case Analysis

Spare Part Price and Total Impact decrease 10%

All combinations showed small gap among each other. Combination nine and ten having the same combination, total risk and inventory cost. Combination nine and ten also having the lowest inventory cost but the highest in terms of total risk.

Spare Part Price and Total Impact decrease 30%

All combinations showed low value in inventory cost as compared to total risk. The lowest inventory cost is at RM4,725,000.00 while the highest value is RM9,905,000.00. Meanwhile the total risk showed high difference between the lowest and the highest point of risk. The lowest was recorded at RM12,225,242.00 and the highest is RM17,410,881.00.

5. Discussion

Here, the focus was on inventory spare parts requirement strategy for plant maintenance. Moreover, it discussed the concept of risk, its processes and multiple approaches. Here, risk assessment was shown to be made up of three main components, namely risk identification, risk estimation and risk evaluation. In this study, it uses all the components accordingly to produce the overall solution. This process, then led to the conclusion that assessing spare parts requirement must be tackled holistically by combining its cost and risk values on the same platform.

Moreover, this research gives a thorough description of the main settings of the plant maintenance and inventory management, with emphasis on current issues of spare parts shortage and excess of inventory. It serves to enhance and expand the readers' understanding of the plant maintenance issues by providing detailed explanations on the concepts and situations of the plant maintenance environment. The knowledge presented in this chapter showed that plant operation settings differ from one arrangement to another and one can identify critical issues to develop better solutions for the spare parts requirement strategy.

Academic Contribution

Risk based technique used in inventory decision making marks the new area of inventory management field of study and has gained popularity in the last decade. This technique emerged due to awareness of importance on financial impact in managing plant operation. The risk based technique acknowledged the weaknesses and strengths of managing inventory of plant operation, and has great potential in improving decision making effectiveness. However, to fully benefit from this approach, impact aspects in this technique must be understood, to ensure the effectiveness of the approach. Therefore, this research has made several contributions to the body of knowledge in the domains of inventory management, specifically in risk based technique.

a) The first contribution of this study provided technical aspect of the developed technique in terms of risk and inventory cost. Then, the value will be optimized according best quantity level is provided. The findings showed that the optimization technique give better combination value as compared to other forecasting technique use.

b) The second contribution provides the concepts of incorporating risk in forecasting of stock for inventory management. To date, less study has been performed on the risk based technique to determine the stock level based on financial risk. The developed technique has showed on how the risk is quantified based on the spare parts breakdown event, probability of breakdown and impact consequences. Therefore, this study provides additional insights on the relationships between forecasting and risk practices in plant operation environment.

c) The third contribution of this study is that it able to provide inventory management studies in plant operation environment settings. Inventory management lacks studies focusing on the risk quantification and optimization for spare parts utilization. Therefore, this study adds a new dimension regarding the inventory management practices, specifically in spare parts utilization.

Managerial Contribution

The proposed method can also be a helpful tool for the inventory planner in the negotiation process of spare part inventory quantity determination with the plant maintenance as it provides information on the significant impact of inventory excess and shortage on the organization's financial risk. Manipulating the spare part inventory cost in the equations above will provide valuable information on the best spare part inventory investment, which will benefit both plant maintenance and inventory management. The application of the proposed method is not limited to the plant maintenance system only, with some modifications, this concept can be applied to any other systems that involve risk mitigation.

Conclusion

In summary, this research provides a risk based technique regarding the spare parts inventory and cost for optimizing quantity level in plant maintenance. The significant results obtained in this research suggested that a good decision making on inventory stock level can be achieved by incorporating the element of risk and optimize the potential loss which can give the best option in terms of spare parts quantity level of spare parts combination. This technique is not difficult to apply because the practices originated from the plant operational practices. The proposed technique recognizes plant operation and inventory management strength and weakness, which bring out better decision in improving organizational performance.

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