



The Classification of Criticality for Spare Parts by Applying the Ratio of Production Lost Cost to Spare Parts Inventory Cost

Sakon Wongmongkolrit^{1*}, Bordin Rassameethes² and Kulnatee Laohakul³

¹Industrial Engineering International Program, Faculty of Engineering, Kasetsart University, Bangkok, Bangkok 10900, Thailand.

²Department of Operations Management, Faculty of Business Administration, Kasetsart University, Bangkok, Bangkok 10900, Thailand.

³Business Research Development Division, Thailand Institute of Scientific and Technological Research, Pathum Thani, 12120, Thailand.

Authors' contributions

This work was carried out in collaboration between all authors. Author SW designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript and managed literature searches. Authors BR and KL managed the analyses the study. All authors read and approved the final manuscript.

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ABSTRACT

This study is mainly focused on finding the ratio between opportunity cost and spare parts inventory cost. Implicitly, the opportunity cost is represented by cost of production lost or loss in opportunity to make profits from reducing in production capacity when machine is in maintenance, while inventory cost is the cost of having some parts as spares in inventory system for ensuring these parts will not be shortage. The main aim is to generate the ratio of production lost cost comparing against inventory cost. This ratio is the boundary or demarcation line between the criticality (or not) of spare part, or can be significantly represented as an indication index to be used for classifying

*Corresponding author: E-mail: sakonwong@gmail.com;

the spare parts as critical parts when index is over than one, or non-critical parts when index is less than one.

Aims: This study is to find the method for classifying the spare parts which one is the critical part. Or finding the necessity of spares in the machine (or system) when there are any breakdowns.

Study Design: To collect the data that is the relevant costs during maintenance downtime from the machine (baggage handling system system), and then exploit these as input data to find the ratio using as a criterion for the decision.

Place and Duration of Study: The Baggage Handling System of Suvarnabhumi International Airport (Bangkok Airport), Thailand. The duration of this study is 3 years.

Methodology: To find the ratio (or index) by comparison between the production lost cost and spare parts inventory cost.

Results: If index or ratio of production lost cost to inventory cost is over than one, then part is criticality. Otherwise, if index is less than one, then part is non-criticality.

Conclusion: This ratio can be significantly used as the reference index to classify the spare parts which one is critical part or not.

Keywords: Spare part; criticality; maintenance; necessity; inventory cost.

DEFINITION OF VARIABLES

All variables using in this research have to clarify before using, so the variables are:

- PL_C : is production lost cost
 P_R : is production rate.
 P_A : is percentage of failed machine affecting to overall production capacity.
 M_{DT} : is maintenance downtime.
 π : is profit margin per unit.
 P_S : is product price sold.
 P_C : is product cost (raw material cost).
 L : is parts delivery lead time.
 IN_C : is inventory cost.
 S : is ordering cost.
 TH_C : is total holding cost.
 C : is spare part unit cost.
 h : is holding cost fraction (percentage of spare part unit cost).
 M_{TBF} : is mean time between failures.
 k : is the identical parts will be changed simultaneously in the same period.
 R_{PH} : is ratio of production lost cost to inventory cost.
 ROP : is re-order point.
 SS : is safety stock.
 λ : is failure rate (of part installed in machine).
 T : is purchasing period.
 T_W : is allowing time of spare parts to be shortage before purchase the new order.
 Q : is economic order quantity.

1. INTRODUCTION

Maintenance cost is one of the most important costs for all manufacturers. Especially, spare parts cost is the main cost of maintenance actions. Basically, spare parts cost composes of material cost and inventory cost, whilst material cost cannot usually be avoided but inventory cost can be minimized by managing some conditions. Obviously, the necessary spare is one of these

conditions. If spare is identified as necessary part then it will be kept at least one unit for ensuring that spare will be in-hand. Contrary, if it is identified as non-necessary part thus it can be shortage. This is an easy example. But in the real world, there are two questions needed the answers. The first question is "How to specify that any spare parts are necessity?", and the second question is "How many pieces of necessary parts are kept?"

According to Fig. 1, this figure represents the confidence level of spare parts availability plotted against the number of spare part held. For example, if the factory holds X spares, thus their confidence of availability will be 100%. Obviously, it cannot be greater than 100%, so if the factory holds more than X spares of the confidence level which will still be 100%. Therefore, any more than X spares are a total waste of money. Whether, or not, the spare is critical, holding more than 100% level produces no benefit [1].

By this meaning, critical part can be inferred as necessity spare. However, the lags of spare parts (which is necessity) will incur in cost of lost production capacity (or lost in making profits during machine downtime), but hold a lot of spares will increase more inventory cost. Therefore, trade-off between the necessity to hold spare parts and anticipation of device (part) failures will be considered in order to minimize the total cost.

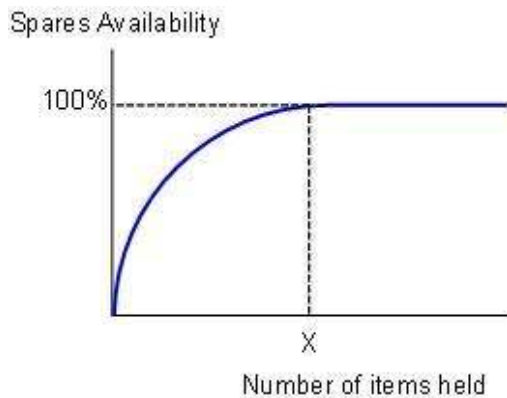


Fig. 1. Spares availability VS Number of items held

Source: Adapted from [1]

2. RELEVANT LITERATURES AND RELATED WORKS

In area of spare parts classification study, the judgment for spare part is criticality or not, this is one of the most interesting topics. Meaningfully, critical spare can be inferred as an important part or necessity (as mentioned in previous). There are many researches and case studies focusing on how to classify the criticality of spares. Many approaches are applied for determining the critical spares such as Analytic Hierarchical Process (AHP) [2,3], Life Cycle Cost Analysis

(LCA) [4], Genetic Algorithm (GA) [5], Risk-Based Optimization Analysis [6], Reliability Centered Maintenance (RCM) analysis [7,8], The Failure Modes, Effects and Criticality Analysis (FMECA) [9], Reliability Analysis [10,11], Root Cause Failure Analysis (RCFA) [12], Modify ABC Analysis [13], etc. Most of previous studies did not focus on some special ratio using as decision criteria for indicating that part is criticality or not. However, some study like [14] suggests multi-criteria inventory model by applying a lot of ratio to be used as decision criteria but it is rather look like ABC, XYZ, analysis than the ratio.

This research paper presents classification method using to be demarcation line or boundary for classifying the criticality (or not) of spare. The production lost cost (or opportunity cost) and inventory cost are obviously evaluated in term of money spending for each individual costs. By using the ratio of production lost cost to inventory cost, this is applied to be the boundary of the classification while the previous studies did not issue this. Moreover, this study also applies an easy arithmetic to be established the easy classification method which is easy to understand and suitable for all factories using a lot of spares. Because this is not the complicated mathematical model that is rather easy to use than previous methods, and can apply this method to classify many kinds of spare parts by taking a short time.

3. COST STRUCTURE

All relevant costs are defined and explained as following statements:

3.1 Production Lost Cost

Production lost cost may probably be called as lost sale cost or loss of opportunity in making profitability. Because this cost is occurred during maintenance downtime or machine fall-in down status. This cost is supposedly calculated by based on no any spare parts to be kept in inventory. Especially, if machine fall-in down status then a new spare will be purchased at all. For this case, it is not necessary to keep any parts as spares. Whilst, production lost cost is calculated by applying the multiplication numbers among production rate, percentage of failed machine affecting to overall production capacity, maintenance downtime, and marginal profit of product per unit or the different price between product sale price and raw material cost.

$$\begin{aligned}
 PL_C &= P_R \cdot P_A \cdot M_{DT} \cdot (P_S - P_C) \\
 &= P_R \cdot P_A \cdot M_{DT} \cdot \pi
 \end{aligned} \quad (1)$$

3.1.1 Assumptions

All products can be sold out by without any remaining products, no any scraps or defective products during the production periods, and lead time is constant.

Example, if there is a motor inside machine to be breakdown, whilst the production rate of this machine is 100 pieces per hour, the capacity of this machine affecting to overall is 10% of whole system, each breakdown will take around 2 hours for recovery, and product price sold is 200 Baht with product cost is 80 Baht per unit, thus the production lost cost is:

$$PL_C = 100 \times 0.10 \times 2 \times (200 - 80) = 2,400 \text{ Baht}$$

Meaningfully, this factory lost in opportunity to make profit equal to 2,400 Baht during maintenance downtime (2 hours).

Basically, maintenance downtime composes of delivery lead time and repair time. Almost of maintenance downtime is spent for the loss in lead time. Because lead time is very longer than repair time then repair time can be waived. However, this study is thought on the basis of no any parts to be kept in inventory. So, if there is some part(s) to be breakdown then new spare(s) will be immediately purchased. Thus, equation (1) can be rewritten as:

$$PL_C = P_R \cdot P_A \cdot L \cdot \pi \quad (2)$$

Equation (2) can be used for finding the production lost cost or loss in making profitability during maintenance downtime (when downtime is represented by spare parts lead time).

3.2 Inventory Cost

Inventory cost always includes all relevant costs such as part depreciation cost, interest rate cost which comes from the need of keeping part as spare. However, inventory cost always composes of ordering cost and holding cost.

$$IN_C = TH_C + S \quad (3)$$

Whereas, total holding cost is the multiplication number of spare part cost and the summation of interest rate cost, part depreciation cost, and the

other relevant costs. All of these costs are represented by the percentage of spare parts unit cost (or holding cost fraction: h). So, total holding cost can be formulated as:

$$TH_C = C \cdot h \quad (4)$$

According to this study, ordering cost will be waived or will not be in calculation by a reason of that part is either to be bought on now (to keep it as spare and use for replacing in future) or postponed to be bought on the future (no any part to be kept as spare on now but it will be bought on the future when failure will occur) so it is not necessary to think about the ordering cost. If factory manager decides to have a spare in inventory, spare part is probably stocked within mean time between failures before it is used for replacing the failed part in machine. Thus, spare part must be kept during equipment's mean time between failures. If parts are needed to change as identical parts equal to k pieces (or using more than one unit in the same position) for every replacement such as battery changing, double driving belts, spark plug and so on. So, equation (4) can be rewritten as:

$$TH_C = k \cdot C \cdot h \cdot M_{TBF} \quad (5)$$

Note: M_{TBF} in equation (5) is measured by based on an annual period.

3.3 The Ratio of Production Lost cost to Inventory Cost

In term of necessity, the production lost cost is compared against inventory cost. Fig. 2 can be used for illustrating and to be represented the concept of necessity. Whereas, ratio of production lost cost to total holding cost (R_{PH}) can be illustrated as:

$$R_{PH} = \frac{PL_C}{TH_C} \quad (6)$$

According to Fig. 2, if production lost cost is over than total holding cost (or $R_{PH} > 1$) thus that part is seem to be a necessary part or it is high necessity to a system. Contrary, if production lost cost is lower than total holding cost (or $R_{PH} < 1$) then that part is seem to be unnecessary part or it is less necessity to a system. Meaningfully, if a part is installed at an none important location in the system whenever that part is in down status then we can wait a new part for replacing the failed part until production lost cost equal to total holding cost. If it is tendency to increase more

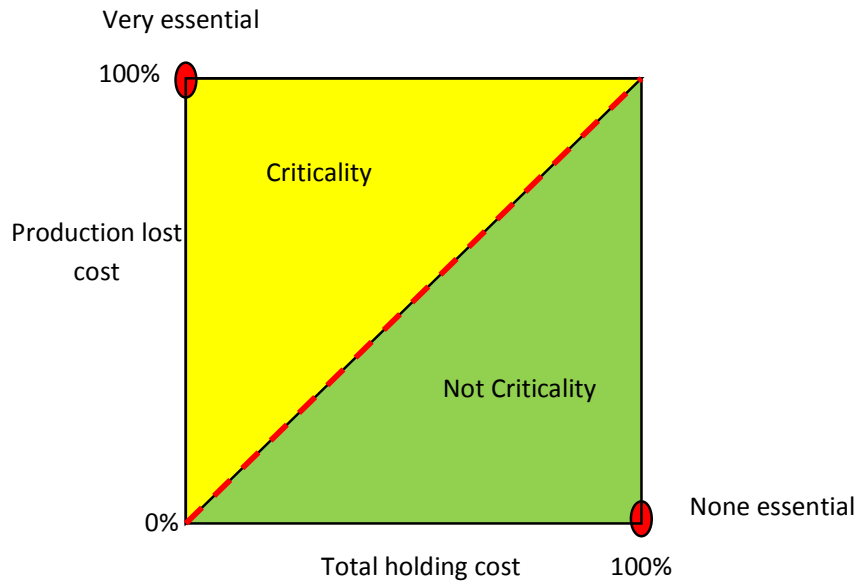


Fig. 2. The classification of critical (necessity) spare parts

Production lost cost during maintenance downtime (after part inside machine failed) which includes delivery lead time, diagnosis time and the other waste time then that part is seem to be very essential. Contrary, it is seem to be nonessential.

Example, if production rate is 100 pieces per day, product price sold is 50 Baht with product cost is 30 Baht per unit, and machine has 10% affecting to overall capacity. There are two comparison cases of delivery lead time to consider, the first case lead time is 15 days and the second is 90 days.

So, production lost cost of first case is:

$$PL_C = 100 * 0.10 * 15 * 20 = 3,000 \text{ Baht}$$

And, the production lost cost of the second case is:

$$PL_C = 100 * 0.10 * 90 * 20 = 18,000 \text{ Baht}$$

Whilst, motor unit cost is 50,000 Baht, holding cost fraction is 10% of part's value per unit per year, and mean time between failures is 30 months (2.5 years). So, total holding cost is:

$$TH_C = 50,000 * 0.10 * 2.5 = 12,500 \text{ Baht}$$

Regarding to the example, 3,000 and 18,000 Baht are the lost cost of reducing in production capacity (or loss of profitability) during

maintenance downtime on the basis of no any spares to be kept in inventory. And 12,500 Baht is holding cost or cost having parts as spare (or motor must be kept during M_{TBF}). So, spare part of the second case can be inferred as necessary part, while spare part of the first case can be inferred as unnecessary part.

4. NUMERICAL RESULTS

The case study is the Baggage Handling System of Suvarnabhumi International Airport (Bangkok Airport, THAILAND), the average baggage pass through outbound conveyors (departure flight) is 45,200 bags per day. And the baggage charge is 50 Baht with cost is 10 Baht per bag.

4.1 There Are 4 Devices (Parts) As the Examples

- Block Gasket, this part is used to be the inserted material between sorter tray and wire loop cart (of automated baggage sorting machine).
- Wire Loop Cart, this part is used as a base of sorter tray, this device looks quite similar as the bogie of the looping equipment in the automatic sorting machine.
- Cover for cart, this part is used for protecting dust and dirtiness from surrounding area.

- Lamp glass LED, this part is used as indicator light to show the existence of electricity passing through the Motor Control Panel (MCP).

4.2 Additional Information

1. The currency in Thailand is Thai Baht, and the exchange rate is 32.5 Thai Baht per 1 US dollar (on December 2014).
2. The number of baggage pass through the conveyor lines is average from July 2013 to June 2014.
3. All appearance example parts which are shown in Tables 1 and 2, all parameters and values involving calculations are measured under the environment and condition of the airport such as workload, temperature, ambient, and so on.

Regarding to Tables 1 and 2, the production lost cost (in Table 1) and total holding cost (in Table 2) are calculated from the outbound conveyor (departure baggage). The value of production lost cost showing in this Table 1 are compared against total holding cost showing in Table 2. The ratio of production lost cost to total holding cost is shown in Table 3.

According to Table 3, Block gasket and Wire loop cart are the necessity part because the ratio of production lost cost to total holding cost is greater than one. Contrary, Cover for cart and Lamp glass LED are none-necessity because the ratio of production lost cost to total holding cost is less than one.

5. APPLICATIONS

Indeed, the most important useful of this study is "How can this concept apply to spare parts inventory management?", and this concept can be apply to reduce the complicated thinking about previous studies. Consequently, the contributions to knowledge of this study are:

- Safety stock
- Re-order point and purchasing quantity

According to Fig. 3, there are two cases of considerations. The first case is to concern about inventory management for necessity part and the second is to concern about inventory management for none-necessity part. For the necessity part, the safety stock will be applied as its buffer, while none-necessity part will not. And both of them are still applied the concept of economic order quantity (EOQ).

5.1 Safety Stock Concept

For the necessity part, safety stock is very importance for ensuring that part will not be shortage. Therefore, safety stock is equal to production lost cost divided by spare part unit cost. So, Safety Stock is:

$$SS = \frac{P_R \cdot P_A \cdot L \cdot \pi}{c} \quad (7)$$

Safety stock in equation (7) is the maximum number. If production lost cost is a big value, then safety stock will be also a big value. For this case, a lot of sunk cost will occur.

Table 1. Production lost cost

Variable	Unit	Part			
		Block gasket	Wire loop cart	Cover for cart	Lamp glass LED
Production rate (P_R)	bag per day	45,200	45,200	45,200	45,200
Lead time (L)	day	25	30	25	3
Amount of identical parts in system (k)	item	3,268	1,634	1,634	3
Affecting rate (P_A)	percent	0.031%	0.061%	0.0001%	0.0001%
Profit per bag (π)	Baht	50	50	50	50
Production lost cost (PL_C)	Baht	17,289	41,493	57	7

Thus, safety stock should be compared against some criteria such as the failure rate on lead time, or amount of similarity parts which are installed in machine. However, the ratio of delivery lead time to mean time between failures is the most reasonable. Then, safety stock is:

$$SS = \text{Min} \left[\frac{L \cdot k}{M_{TBF}}, \frac{P_R \cdot P_A \cdot L \cdot \pi}{C} \right] \quad (8)$$

For the non-necessity part, spare parts can be shortage, and the re-order point can be delayed until the maximum time of allowing spares to be shortage ($T_W + L$) which is the time that production loss cost equal to holding cost (if the amount of those equal to the need to have parts as spare). And, allowing time ($T_W + L$) is equal to:

$$(T_W + L) = \frac{C \cdot h \cdot k \cdot M_{TBF}}{P_R \cdot P_A \cdot \pi} \quad (9)$$

Or:

$$T_W = \frac{C \cdot h \cdot k \cdot M_{TBF}}{P_R \cdot P_A \cdot \pi} - L \quad (10)$$

Whereas, T_W is defined as the allowing time of spare parts to be shortage before purchase the

new order (or time before re-ordering point). The allowing time ($T_W + L$) is very important, because we can exploit it as time of reducing in holding cost (of EOQ model) by delaying in re-order point until equal to this time. And the holding cost can be reduced until equal to:

$$C \cdot h \cdot k \left[\frac{T_W + L}{T} \right]$$

5.2 Re-order Point and Purchasing Quantity

The purchasing quantities of both cases are similar, and conform to the EOQ model. So, purchasing quantity is:

$$Q^* = \sqrt{\frac{2Sk\lambda}{ch}} \quad (11)$$

According to Fig. 3, the re-order point of necessity part and non-necessity part, both of them are ordered at delivery lead time.

Table 2. Total holding cost

Variable	Unit	Part			
		Block gasket	Wire loop cart	Cover for cart	Lamp glass LED
Spare part unit cost (C)	Baht	410	31,000	2,230	130
Holding cost fraction (h)	percent (per item per year)	5.0%	10.0%	3.0%	2.0%
Mean time between failures (M_{TBF})	year	1.5	0.08	2	5
Total holding cost (TH_C)	Baht (per year)	31	258	100	13

Table 3. Production lost cost

Part	Material unit cost (C)	Ratio of PL_C to TH_C (R_{PH})	Necessity	
			Much	Less
Block gasket	410	562.2	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Wire loop cart	31,000	160.6	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Cover for cart	2,230	0.56	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Lamp glass LED	130	0.52	<input type="checkbox"/>	<input checked="" type="checkbox"/>

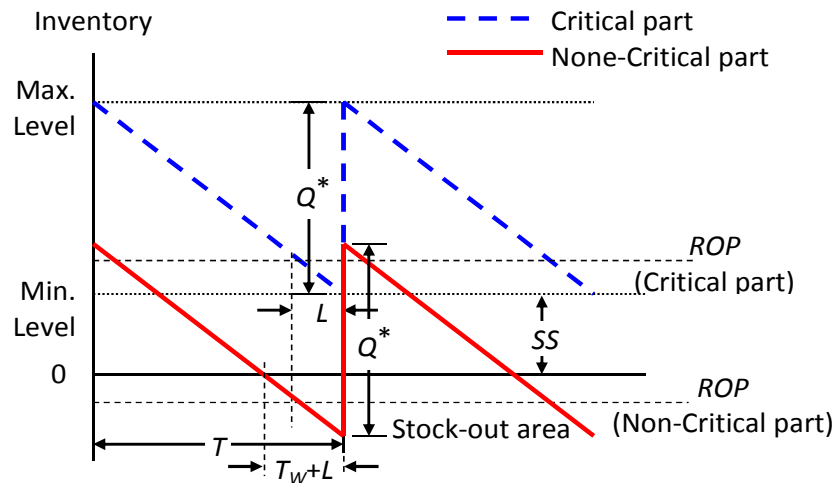


Fig. 3. The modification of EOQ model

6. CONCLUSION

This ratio can be significantly used as the reference index to classify the spare parts which one is critical part (or not). If index or ratio of production lost cost to inventory cost is over than one, then part is criticality. Otherwise, if index is less than one, then part is non-criticality. For critical spare, this will be kept by applying safety stock concept as equation (8).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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