

**STRATEGIC INVENTORY OPTIMIZATION: HARNESSING
CLASSIFICATION METHOD FOR SPARE PARTS OPTIMAL STOCK
LEVEL DECISIONS**



**AN INDEPENDENT STUDY SUBMITTED IN PARTIAL FULFILLMENT OF
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ABSTRACT

This research study focuses on finding an approach and method to manage spare parts inventory at an appropriate level at the point that has the lowest spare parts inventory costs. The methods, models, and mathematical equations are focused on being easy to understand, not complicated, and able to be used easily. The model that was created was based on the principle of classifying spare parts into different types according to the pattern of use for the spare parts. There are three main considered factors to classify: price of spare parts, necessity for the system, and speed (or frequent) of use of spare parts. Such classification will result in the form and usage of eight groups or eight baskets of spare parts types, which will be called the eight baskets inventory system. After that, the spare parts that have been divided into eight groups will be used to find the appropriate inventory level according to the models and mathematical equations that have been determined to suit each group of spare parts. This method has been used to find appropriate inventory levels and has been tested by simulating various related values, especially total inventory costs. And it has been proven to have lower inventory costs than studies, research, and models have thought of in the past. This study is suitably used for finding spare parts inventory levels for highly complex systems. A large number of types for spare parts are used. In addition, the determination of inventory strategies according to the models and heuristics in this study does not emphasize difficulties in implementation and still emphasizes simplicity in understanding and the more reliable principle and is better than past work.

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Sakon Wongmongkolrit



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CHAPTER 1

INTRODUCTION

1.1 Background and Significance

Basically, “spare parts” is the short name of maintenance, repair, and operation items (or MRO items). Spare parts always refer to the extra components or items kept in reserve for replacing failure, faulty, breakdown, worn-out, and malfunctioning parts in machinery, equipment, vehicles, or other systems. These parts are typically stored as a precautionary measure to ensure that, in the event of a breakdown or failure, the necessary replacements are readily available to restore the functionality of the system. Spare parts can include a wide range of items, such as:

- Components: Individual pieces or parts that make up a larger system, such as a breaker, lamp, gear, shaft, motor, and so on.
- Consumables: Items that are expected to wear out over time, such as filters, belts, spark plugs, grease or lubricants, engine oil, batteries, and so on.
- Modules: larger assemblies that can be swapped out as a single unit, such as a PLC, barcode reading set, inverter, and so on.
- Safety devices: It is the supplemented devices to help prevent dangers from insecurity, such as a sensor, warning alarm, buzzer, and so on.
- Tools and supporting maintenance materials: specialized tools that may be needed for maintenance or repairs, such as a tachometer, torque wrench, rustproof paint, cleaning cloth, and so on.

Ensuring the availability of spare parts is vital for reducing downtime and maintaining the effective functioning of diverse systems and equipment, particularly in sectors such as manufacturing, transportation, and infrastructure. Efficient inventory management of spare parts is essential to upholding the smooth and dependable operation of machinery and systems. These spare parts are utilized for repairing various types of mechanical, electrical, electro-mechanical equipment, and control systems when they experience issues like being out of order, out of control, malfunctioning, or facing breakdowns (referred to as repair actions or unscheduled maintenance). Additionally, they are used for routine actions to keep the equipment in working order (known as scheduled maintenance) or to prevent issues from arising (preventive maintenance). Overall, spare parts play a crucial role for manufacturers, supporting maintenance actions to restore equipment or machines from a state of failure to normal operation. Manufacturers cannot afford to stock excessive spare parts due to the

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substantial sunk costs involved in their purchase without any corresponding increase in machine productivity or production capacity. Therefore, it is imperative to implement an optimal stock policy to minimize the overall maintenance cost.

Furthermore, spare components are typically stored in compliance with the necessary quantities to support various maintenance tasks. Occasionally, these spare parts may be maintained as a percentage of gross plant investment (GPI), as indicated in Table 1.

Table 1.1 Percentage of spare parts compare with GPI

Zone	Industrialize Country (%)	Average (%)	Developing Country (%)
Type of spare parts			
Machinery Spare Parts	2	4	10
Accessories or Miscellaneous	1	3	8

Source: United Nation Industrial Development Organization (UNIDO), and International Fertilize Development Center (IFDC), (1998).

In reference to Table 1.1, the computation of this percentage encompasses all categories of spare parts, with the average utilization of spare parts (per GPI) amounting to 4 percent. This criterion is applicable for machine-based factories (where the majority of products are machine-produced), while a threshold of less than 1.5 percent is recommended for human-based factories (where the majority of products are manually produced).

Furthermore, the in-depth meaning given by the relevant organization, institution, or agency. The definition of spare parts has been defined by various agencies, such as:

- The Cambridge Dictionary gives the meaning of spare parts as “an extra piece that can be used to replace a piece that breaks, esp. in a machine” or “a part that can be used to replace another similar part in a car or other machine or piece of equipment”.
- The Oxford Dictionary gives the meaning of spare parts as “a new part that you buy to replace an old or broken part of a car, machine, etc.”
- The European Federation of National Maintenance Societies gives the definition of spare parts as “all materials which have the objective of retaining or restoring an item in or to

a state in which it can perform its required function. The actions include the combination of all technical and corresponding administrative, managerial, and supervision actions”.

- Federal Standard 1037C and MIL-STD-188 (the Department of Defense Dictionary of Military and Associated Terms, May 2001) give the description of spare parts as the following statements: In terms of telecommunications and engineering, spare parts may refer to any materials that can be used for supporting maintenance and repair activities. The materials that can be used are:

1. Used for all action taken to retain material in a serviceable condition or to restore it to serviceability. It includes inspection, testing, servicing, classification as to serviceability, repair, rebuilding, and reclamation.
2. Used for all supply and repair actions taken to keep a force in condition to carry out its mission.
3. Use for supporting the routine recurring work required to keep a facility (plant, building, structure, ground facility, utility system, or other real property) in such condition that it may be continuously used at its original or designed capacity and efficiency for its intended purpose.

Hence, spare parts can be defined as materials or substances that aid in all maintenance activities, facilitate repair actions, and prevent failures to maintain and support the smooth operation of a manufacturing plant. Generally, spare parts may encompass a wide array of items, including fasteners, conveyors, and lubricants; cleaning supplies; plumbing materials; tools; and supporting equipment essential for the seamless functioning of a plant.

1.2 Research Questions

Managing spare parts and controlling inventory in the context of a complex system poses a significant challenge for manufacturers, particularly in sectors such as airports, electric train maintenance centers, and large power plants with numerous substations, sizable factories, and central warehouses with multi-tiered facilities. These environments typically store a vast array of spare parts and components. Spare parts encompass not only materials used for replacing malfunctioning machinery but also supportive materials essential for both repairing machines after breakdowns and maintaining machines to prevent failures. In this broader sense, spare parts can be interpreted as all materials, including machine tools that support various maintenance activities. The complexity of spare parts management arises from the diverse sub-types, sub-classes, and utilization characteristics associated with different spare parts. For example, lubricants come in numerous grades and classes, each serving specific purposes. Some function as external lubricants, while others serve internally or externally. Moreover,

specific lubricants may be applied to reduce machine temperature, while others focus on protecting machinery against oxidation, rust, or other potential issues. The multifaceted purposes for which spare parts are employed highlight the intricate nature of spare parts management, as each intended use requires distinct types of parts.

Practically, the management of a larger quantity of spare parts becomes more intricate and incurs higher costs. Therefore, effective management practices should be implemented to minimize the required number of spare parts. While manufacturers cannot entirely forego stocking spare parts, the objective is to maintain the smallest possible stock under the required service level, ensuring that spare parts are available for all maintenance actions. A significant challenge in spare parts management arises in determining the appropriate inventory level to meet the demand for these parts. This is a complex issue as some parts face independent demand, others are strategically located, some are high in cost, and some are infrequently used. Consequently, managing spare parts to meet their demand is not a straightforward task. Particularly in complex systems, a substantial quantity of spare parts is consumed for various maintenance actions, maintaining production capacity, and ensuring the smooth operation of machines, production lines, or systems.

Primarily, this study is conceived around the management of spare parts inventory within the maintenance framework. It is an adaptation and enhancement of ABC analysis, which, unlike ABC analysis, prioritizes spare part necessity (critical parts) rather than solely focusing on material quantity and cost. Notably, certain parts, though infrequently used, are crucial for a machine. In the event of a breakdown of a critical part, immediate replacement is imperative, such as in the case of a main circuit breaker. Therefore, these essential parts need to be stocked to meet the required quantity. Inventory management in this context is influenced by three factors: movement, necessity, and cost. Unlike ABC analysis, movement is not solely based on the usage quantity of parts but also considers the flow of materials (or parts usage), acknowledging that some parts, despite not being the majority, have a higher likelihood of failure (or breakdown). Necessity (or criticality) refers to parts that are integral to a system; their failure necessitates immediate replacement. Generally, necessary parts should be stocked with a minimum of one unit, but the quantity may vary based on the part's installed location. The final contributing factor is cost, reflecting the unit cost of materials and determining whether the parts are considered valuable (high-cost) or not.

Furthermore, the classification analysis of spare parts is thought by based on the following guidelines:

- VED (Vital, Essential, Desirable) analysis, which uses guidelines to consider the importance of inventory in storage systems, is applied to spare parts storage. There is a way of thinking based on the importance of using those spare parts, whether they need to be used on production lines or machines that are important and not important, divided into 3 levels: very important, moderately important, and general.
- HML analysis is a method for categorizing inventory by classifying spare parts into three groups: high (H), medium (M), and low (L), determined by their unit prices. Businesses commonly define three price ranges to classify parts into H, M, and L categories. The H category comprises parts with the highest unit prices, representing the most expensive ones in the inventory. Parts with medium unit prices are assigned to the M category, while those with the lowest unit prices are assigned to the L category.
- FSN (fast moving, slow moving, and non-moving) analysis refers to an inventory management technique that divides products into three categories: fast moving, slow movement, and does not move depending on the speed at which it is used or sold and storage period. This analytical approach can be used well and is suitable for spare parts storage because moving parts such as lubricants and machine (or engine) heat reduction substances have fixed replacement intervals. While some types of spare parts, like circuit breakers, are used very little.

The classification analysis (or method, as mentioned in the previous paragraph) of various types of spare parts by calculating the amount of storage spares is quite similar to the ABC analysis, which is approximately equal to 70, 20, and 10 percent. The consideration of storage spares for each type of analysis has different advantages and disadvantages. Details of the gaps and weaknesses for each analysis in spare parts inventory management will be explained in more detail in the next chapter.

Additionally, the starting point of the study was that using the EOQ model alone to calculate the optimal inventory of spare parts may not provide the lowest storage costs, and this model may not have considered spare parts that are critical parts in the system (or are important to systems and machines). Even though using the EOQ model there is a safety stock, it is not calculated according to the criticality (or not) of the parts. But only based on the probability that there will be a breakdown or failure during the lead time. The weaknesses and gaps of the EOQ calculation for spare parts inventory management will be presented in detail in the next chapter. This study attempts to fill this gap by combining it with the grouping of spare parts before calculating it using the EOQ model to calculate the appropriate amount of parts storage.

Consideration of the approach used for these research problems must answer the following questions related to the problems:

1. The problem of demand for spare parts arises from the pattern of breakdowns and failures of machines or systems that have a breakdown function and a probability distribution of breakdowns.
2. There is a problem with the format for grouping many classes and types of spare parts. Then use this grouping to calculate appropriate spare parts storage and save on procurement costs.
3. The problem is determining appropriate boundary lines for grouping. The method of finding boundaries will determine whether the spare parts are: expensive or cheap, frequency of use (or movement) more or less, and spare parts that are important or not important. This includes proving that this divided line can actually create more savings.

Consequently, this study will establish the boundary lines for separation or classify the spare parts types and then take them into the eight separation models of spare parts inventory management, which are easier to understand than the previous studies. By this concept, all inventory models appearing in this research are the cognitive thinking of these eight models, which will reduce the number of spare parts inventory levels in the storage system, reduce the expenses of maintenance, eliminate the complicated management of spare parts inventory, and determine the inventory policy to be easier than the previous one.

1.3 Research Objectives

Obviously, this study establishes its own framework to elucidate the demand for various spare parts, attributing it to machine failures or system component failures in a probabilistic manner, aligning with relevant theories on system reliability. The demand classification stems from machine failures, encompassing both dependent demand (replacing parts at specified intervals) and independent demand (replacing parts in the event of a breakdown). Hence, the approach in this research involves integrating rationing into the existing practice for two demand classes: dependent and independent. The rationale for adopting this approach is rooted in the belief that it will lead to enhanced system performance, meeting specific service level requirements. Additionally, this study gives equal priority to essential spare parts (critical parts) and non-essential spare parts, based on cost-effectiveness, considering both frequently and infrequently used spares.

But at this point, the commitment is established, and the creation of the plan for acquisition and inventory management with uncertain demand for spares and both positive and negative demand on lead time is subject to this framework. Conversely, an alternative perspective involves grouping or categorizing the procurement of each type of spare part before incorporating them into the analysis, utilizing appropriate mathematical methods to quantify the spare parts inventory. It is noteworthy that the study does not delve into the inventory management of spare parts with specific demand, excluding unforeseen events such as fire, lightning, short circuits, accidents, or employee negligence, which might affect their duties. These aspects constitute a crucial component of the study and fall into the critical category with high priority.

Therefore, the main objective of this present study is to develop a spare parts inventory management policy with decision models for the integration of unreliable production systems over time-dependent failure and the suitability of procuring spare parts during that period with consideration of the optimal estimation of product support maintenance or required spare parts under the required service level. This research is broadly concerned with the development of improved tools and techniques that will establish maintenance optimization and enable the effective analysis of the planning for spare parts management and its inventory level with the delivery lead time on the basis of cost effectiveness.

According to the narrative descriptions in recent paragraphs, the proposed objectives of this research study are as follows:

1. To study the characteristics of spare parts consumption and the occurrences of demand due to considered conditions under the reliability function and failure distribution.
2. To find and prove the boundary between the classified variables that make the separation in each group of the spare parts types, results in a reduction in inventory costs.
3. To analyse and classify the groups of individual spare parts types according to steady demand under their main contribution factors and take them into the appropriate inventory model that optimizes the number of spare parts.

1.4 Research Hypothesis

For this research, it is necessary to separate groups of various types for spare parts and then put the separated groups into an appropriate inventory model to find the inventory with the lowest total cost. Therefore, it must necessarily be understood in the context of the variables

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involved, which are important elements for segmenting spare parts. There will be three variables in this research to be considered:

1. The price (or cost) of spare parts is what tells whether the spare part is cheap or expensive.
2. Necessity of that part in the system is what tells whether that part is necessary in that machine or system or not.
3. Frequency of using spare parts is what indicates how often a part is used in a machine (or system). At times, this variable may be referred to as the "moving" aspect of utilization.

The preceding paragraph indicates that the primary context of this research is to establish the boundaries of classification between low-cost and high-cost parts, identify essential and non-essential spare parts within the system, and categorize parts based on their frequency of use (fast and slow-moving usage). By delineating these boundaries, the study aims to reveal the inventory system pattern for spare parts, dividing them into a total of eight groups. A detailed discussion of these groups will follow in the subsequent chapter.

At this point, it is possible to formulate the basic hypotheses of this study, which can be shown as follows:

1.4.1 There is a negative variable relationship between the spare parts unit price and the number of spare parts used.

1.4.2 There is a positive variable relationship between the importance of spare parts required in the system and the number of spare parts used.

1.4.3 There is a positive variable relationship between the spare parts unit price and the importance of spare parts required in the system.

1.5 Scope of Research

In the study, it will be focused on separating (or classifying) spare parts groups in order to take each group into the appropriate inventory model. Therefore, the main aim is to separate groups of related spare parts. There are case studies of spare parts management and spare parts inventory control for the ABC Airport passenger baggage conveyor system, which is an example of the case study.

1.5.1 Scope of Population

The samples for this study are spare parts to be used in the passenger baggage handling system at ABC Airport. By sampling 285 different types of spare parts out of approximately 1,114 types of spare parts in the system, spare parts that are structural parts of the system, such as steel frames that support the system, conduits, wire ways, etc., will not be considered. This case study will be a one-time sampling, and the sample size is based on the sample size table created by Robert V. Krejcie of the University of Minnesota and Earyle W. Morgan of the University of Texas (1970: 608–59). Choosing this method is convenient because if the population number is known, then it can choose the number of samples by being able to see the number of samples directly from the table without additional calculations.

Note: 285 is the total number of sampling spare parts, and 1,114 is the population size. The details of the sampling size and number of populations will be presented in Chapter 3 (Methodology).

1.5.2 Scope of Areas

The survey area is the passenger baggage conveyor system such as mechanical system, electrical system, control system, and supporting materials (e.g., greases, lubricant, tools, and fixing substances) at ABC Airport.

1.5.3 Scope of Variables

Variables include the price of spare parts, the necessity of spare parts in the system, and the frequency of use of spare parts. In addition, the probability distribution pattern of broken machines or parts in the system will be a binomial distribution, which will be taken into account to determine the demand for spare parts.

1.5.4 Inventory Models

Inventory models formed in this study, there will be 8 groups of spare parts, which will require 8 inventory models that will be consistent with the grouping of spare parts and following the theoretical concepts that support this inventory. The consideration will be mainly based on the principles of the EOQ model.

1.5.5 Exceptions in this study

There are limitations in many aspects, whether it will be the time that must be studied, the amount of data to be collected, the mathematical complexity, related theoretical concepts, or, most importantly, finding the answer. Therefore, in this study, there is a need to define exceptions to make it easier to find research answers. The exceptions include:

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- The component (or part) failure rate is constant during component's entire life time.
- All machines are same production rate, same characteristics, have same work load.
- If there are k identical components in the system, all of them are independent, uncorrelated, same characteristics, and similar behavior of failure.
- Spare part cost is constant during the consideration period.
- Spare parts lead time (or supply time) is constant.
- Spare parts demand depends on the failure rate of machines or when it's time to change according to the specified period, demand from accidents is not considered.
- A new spare part will be replaced, no spare parts will be repaired and reused.

1.6 Research Benefits

This study will present a solution for planning to acquire spare parts. The aims of the research will have been concerned with the certain demand to find close-to-optimal stocking policies in terms of cost-effectiveness and the lowest spare parts inventory level system under the desirable service level. The inventory cost structure, optimality, and terminologies will have been described, explained, detailed, and disseminated in this paper.

The objective is to minimize the total inventory costs while considering the required service level. The inventory holding costs are subject to a target level (or sufficient level) to meet the spare parts need and correspond with the variation and waiting times (or lead time). The repaired materials or reused parts will not be useful for the stock inventory policy for this study and will not be considered. The consideration of classifying spare parts groups will be taken into account in this study to reduce the complexity of spare part management. This research study structures whole spare parts demand with the optimization inventory models as combinatorial systematic problems.

Of course, the study's concepts, framework, arithmetic, and models will have been conceived, evolved, and assessed to align with the spare parts acquisition policy and ensure correspondence between overall inventory costs and cost-effectiveness. The method employed for cost reduction by entrepreneurs involves performance benchmarking and optimization of spare parts inventory. The models developed in this study have been generated based on the concepts of spare parts inventory and maintainability, aiming to be applicable across various industries, especially complex systems that utilize a lot of spares. Consequently, the advantage of this approach lies in the reduction of maintenance costs and the enhancement of accuracy in ordering spare parts, ultimately improving maintenance efficiency.

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So, the research study will contribute to knowledge in four ways:

1. It will show the component and system reliability functions. This concept will be useful for understanding system reliability and failure probability distribution.
2. It will show that the consistency between managerial solutions for spare parts inventory control policy enables enhanced operative performances.
3. The classification and separation boundary will be shown, along with the definitions for a set of low or high spare parts costs, non-critical or critical parts, and slow or fast movement (usage).
4. This can be applied to large data sets in very large systems with many spare types. Without being dependent on using a single mathematical equation for calculation, which in this case study will result in more accurate calculations.

1.7 Definition of Terms

Understanding the meaning or specific descriptions of some of the equipment and material characteristics presented here is necessary. In order for those who will read or use the information obtained from the study, including the details obtained from the research, to use it appropriately in the future, the description includes:

1.7.1. A spare part, spare, service part, repair part, or replacement part—the definition of a spare part was already given in the early mention (in the background and significant).

1.7.2 Machine failure, or equipment failure, is any event in which a piece of industrial machinery underperforms, whether entirely or partially, or stops functioning in the way in which it was intended to. The term “machine failure” can encompass differing scenarios and levels of severity (Dave W., 2021).

1.7.3 Failure rate is a measurement of the speed at which the fact of something not working, or stopping working as well as it should, or changes, or the number of times it happens or changes, within a particular period (Cambridge online dictionary), It is usually denoted by the Greek letter λ (lambda) and is often used in reliability engineering. The failure rate of a system usually depends on time, with the rate varying over the life cycle of the system.

1.7.4 Mean Time Between Failures (MTBF) is a measure of the reliability of a system or component. It's a crucial element of maintenance management, representing the average time that a system or components will operate before it fails ([Online]. Available : <https://www.ibm.com/topics/mtbf>).

1.7.5 Spare parts demand refers to the need for an extra piece that can be used to replace a piece that breaks, especially in a machine (at a failure time), with a particular quality (Cambridge online dictionary). It is caused by the main factor of failure of parts in machines or systems worn out parts changed according to the specified period and causes of accidents such as being transported, short circuits, or lightning strikes, etc.

1.7.6 Spare part inventory refers to a list of stock items maintenance technicians use to replace failed equipment parts. Manufacturing facilities keep spare part supplies—like belts, motors, gears, and grease — on hand so they can fix equipment failures without needing to order and then wait for a part to be delivered.

1.7.7 Spare part cost refers to the expenses associated with acquiring and maintaining additional components or items that can be used to replace or repair defective or worn-out parts in machinery, equipment, vehicles, or other systems. These spare parts are kept in inventory to ensure the uninterrupted operation of the equipment or system. The spare part cost includes various expenses related to the procurement, storage, management, ordering cost, and usage of these spare parts.

1.7.8 An important spare part, or necessity part is a specific component or item kept in inventory that is deemed crucial for the maintenance, repair, and continuous operation of machinery, equipment, or systems. The importance of such spare parts is often associated with their role in preventing or minimizing downtime, ensuring the reliability of critical systems, and supporting overall operational efficiency. These spare parts are identified based on their significance to the functionality and performance of the equipment they are intended to support.

1.7.9 Speed of using spare parts or moving of spare parts usage refers to the rate or pace at which spare parts are deployed or consumed in maintenance and repair activities within an organization. It is a measure of how quickly spare parts are utilized to replace or repair worn-out, damaged, or faulty components in machinery, equipment, systems, or structures. The speed of using spare parts is a critical aspect of maintenance efficiency and operational responsiveness. Several factors contribute to the definition of the speed of using spare parts.

1.7.10 The appropriate inventory models refer to the suitable inventory model for spare parts in each group that has been divided according to three main factors: the speed of spare parts use, price, and importance of spare parts, which can be divided into eight forms of inventory according to the nature of spare parts usage.

CHAPTER 2

LITERATURE REVIEW

In an area of maintenance approach research, the study of spare parts management is one of the most significant approaches to maintainability focusing on inventory management, system stability, and reliability. Numerous articles and studies aim to explore innovative approaches to inventory management. In a literature review, it was discovered that Kumar S. (2004) delved into diverse formats of concepts related to spare parts. The author categorized these approach groups and called them "Best practices in spare parts management," dividing the studies into fourteen distinct groups that cover various aspects of spare parts management and its characteristics.

However, this framework was already thought of around twenty years ago. For the past 20 years, in terms of spare parts management, it has been considered a sufficiently long period. Whether it is technological changes, the development of new methods of spare parts management, or new frameworks derived from studies and research conducted during that period. Another important consideration is that engineering maintenance work may have new definitions and reinterpretations. There is actually a lot of research in this area, and a significant amount of research has indeed occurred. Articles and related works after 2004 have been collected, reviewed, and reinterpreted to reflect the current spare parts management context of the study. Therefore, this framework shall be updated, and to suit this research study, it has been adjusted according to this study that can be concluded here.

1. Spare parts demand forecasting, and arithmetic model of spares arising: Models, heuristics, algorithms, and analysis that can meet different kinds of demand profiles such as intermittent demand models, and continuous demand models, including the model for corrective maintenance and time-based maintenance. Examples of models used for analysis include system reliability analysis, moving average analysis, etc.
2. Multi-model-based spare parts demand management, and storage management: Ability to plan for parts based on a variety of models, various types, or there are many different items such as criticality model, cost model, movement model, or a mix of variety models, storage, and space management like inventory layout design, and warehouse layout arrangement.
3. Analysis and classification of spare parts sources and characteristics: Ability to spare parts inventory classification by sources of spare parts, and levels based on one factor such as VED analysis, FSN analysis, or HML analysis; two relative factors such as volume and material cost like ABC analysis.

4. Spare parts inventory control based on service levels, delivery lead time, and parts consumption: Ability to analyze and inventory level based on service levels, parts delivery lead time for inventory planning and parts consumption, safety stock, and probability of spare parts shortage.
5. Capabilities for operation tactical inventory planning: Integration with production and operational plans to optimize equipment availability, optimization of the inventory, spare parts storage, usable life, moving parts, storage space, etc.
6. Optimization models for multi-echelon inventory, and Spare parts distribution system: Deployment inventory at various locations based on need, criticality, service response, etc., availability due to location transfers, supply chain, and geographical distribution.
7. Variety models for reusable parts or combinations with new parts, interchangeable spares: Variety models, or across various stages such as cost analysis, stocking, consumption for part repair, parts return, parts reuse, recycled parts, refurbishing spare, and interchangeability of interchangeable parts.
8. Integration with predictive maintenance applications: Accessing part design data, the ability to provide the design change, and part changes based on repair and part substitution in remaining machine useful life, integrated with various testing systems and capable of storing predictive analysis and observational data.
9. Integration with total preventive maintenance programs: Ability to use spare parts (esp., consumable materials) in integration with the preventive maintenance schedules that are tightly integrated with operational programs, service maintenance records, inventory system, product data management systems, and so on.
10. Spare parts management by using the performance metrics: To measure maintenance activities by using performance metrics such as failure rate, MTTR, MTTF, Unplanned maintenance downtime, Availability, and percentage of service cost to monitor the efficiency of the maintenance and service processes. Including spare parts logistics and supply chain management.
11. Share the best practices: Ability to share the best practices or a case study of standard service practice across the different groups, proposing the best idea, concept, and framework for spare parts or maintenance management. Integrate with the other best applications such as Lean management, Five S, FIFO system, and other good applications for spare parts management.
12. Spare part expiry, supersession, deterioration, obsolescence: Ability to extend, help maximize usable life, predict part obsolescence or discontinued spares, and be superseded by a new part, and the spare parts control balances with the deteriorating inventory.

13. Ability to handle end-of-life, part alternates, and substitution: Ability to capture substitution relationships at the planning level, end-of-life parts inventory control, warranty period spares, and post-product life, including incorporating substitution logic during service execution.
14. Spare parts based on reliability and life cycle analysis: Ability to analyze the equipment life cycle, lifetime prediction, and reliability under both controllable and uncontrollable situations such as environment, working conditions, humidity, and so on. Spare parts are needed for different conditions.

In alignment with the preceding paragraph, the reviewing and investigating of spare parts management articles and their approaches can be systematically categorized which can be taken into account in four phases related to Maintenance, Repair, and Operations (MRO) or spare parts studies. Whereas, each phase can be illustrated as follows:

1. Spare parts demand and Group classification study: This focuses on studying the needs for spare parts, grouping them based on usage, patterns, or sources of arising. This phase emphasizes understanding the origin of spare parts, and so on. This includes categorizing spare parts according to their nature, characteristics, and usage.
2. Spare parts planning study: This group aims to create procurement planning, parts ordering, spare parts inventory planning, spare parts distribution and dispatch planning, parts movement, and space arrangement, combined with production planning and supply chain systems, among other aspects.
3. Integrate with the other applications study: This pertains to the study group concerned with integrating spare parts management with other relevant plans such as preventive maintenance, predictive maintenance, or other plans associated with spare parts usage. Presenting the method for spare parts management at its best in practice, and measurement of various values and results for maintenance work.
4. Life Cycle Analysis and end of service life study: This is a group of studies related to analyzing the lifespan of spare parts, the durability of parts, life cycle analysis of parts, considering ways to extend the lifespan of parts, part replacement studies, and examining factors influencing the life cycle of parts, among other aspects.

Regarding the Kumar S. (2004) framework, each group of research studies and articles is taken into account and then grouped according to the MRO study phase. And, upon reviewing additional documents and related works to enhance the completeness of the grouping of studies and research on spare parts management and to provide guidance for stakeholders or those who may utilize this information as a reference for future studies. The author has summarized the

aforementioned guidelines in Table 2.1. This table has compiled related works, arranged them systematically, and included the list of authors of articles studied in this field.

Table 2.1 Approaches using in Spare parts management

App. No.	Phase of MRO Studies	Theme	Framework, Concept, Methodology	Authors
1		Spare parts demand forecasting, and arithmetic model of spares arising	Models, heuristics, algorithms, and analysis that can meet different kinds of demand profiles such as intermittent demand models, and continuous demand models, including the model for corrective maintenance and time-based maintenance. Examples of models used for analysis include system reliability analysis, moving average analysis, etc.	Eaves AHC, Kingsman BG.(2004) Ghodrati B, Kumar U.(2005) Lucia De A.,et al.(2005) Ahmad R, Kamaruddin S.(2012) Romeijnders W.,et al.(2012) Lengu D., et al.(2014) Rego J.R., Mesquita M.A (2015) Kim T.Y., et al. (2017) Costantino F., et al. (2018) Auweraer S.V., Boute R.,(2019) Turrini L., Meissner J. (2019) Qarahaslanlou A.N., et al.(2022)
2	MRO Demand and Group classification	Multi-model-based spare parts demand management, and storage management	Ability to plan for parts based on a variety of models, various types, or there are many different items such as criticality model, cost model, movement model, or a mix of variety models, storage, and space management like inventory layout design, and warehouse layout arrangement.	Tahirov N.,et al.(2016) Zhang S., et al. (2016) Miralam M.(2017) Niu Ph., et al. (2020) Xiao B, Liu C(2020) Sufa M.F., Mulyana M.K.(2021) Shilovsky V., et al.(2021) Rahman I.U.,et al.(2022) Junke W.,et al.(2023) Kurt B.,et al.(2023) Mongkolkitaveepol P.,et al.(2023) Strassenburg N., et al. (2023)
3		Analysis and classification of spare parts sources and characteristics	Ability to spare parts inventory classification by sources of spare parts, and levels based on one factor such as VED analysis, FSN analysis, or HML analysis; two relative factors such as volume and material cost like ABC analysis.	Mohita G.S., Kashi N.S. (2014) Fernanda O., Clara B.V. (2015) Kareem B., Lawal A.S.(2015) Prakash T., and Ramesh K. (2016) Mohammad A., et al. (2017) Puspitasari A.S., et al. (2019) Rajest H., Vivak A.S. (2019) Wisam Al-D., Walid E. (2020) Pragati J.and Maheshwar J. (2020) Bayu P.P., et al. (2021) Mekete A.D.and Belete S.Y. (2021) Rahul S.M., et al. (2021)

Table 2.1 Approaches using in Spare parts management (Cont.)

App. No.	Phase of MRO Studies	Theme	Framework, Concept, Methodology	Authors
4		Spare parts inventory control based on service levels, delivery lead time, and parts consumption	Ability to analyze and inventory level based on service levels, parts delivery lead time for inventory planning and parts consumption, safety stock, and probability of spare parts shortage.	Wong and Rassameethes (2011) Arts J.J.(2013) Landrieux B., Vandaele N.(2013) Mohd-Lair N.A.,et al.(2013) Digiesi S.,et al.(2015) Kozlovskaya N.,et al.(2019) Sato Y., Jauhari W.A. (2019) Hasbullah H, Santoso Y.(2020) Rammner M.(2021) Emar W, et al.(2021) Hayatie M.N., et al.(2023) Sen E.G. (2023)
5	MRO Planning	Capabilities for operation tactical inventory planning	Integration with production and operational plans to optimize equipment availability, optimization of the inventory, spare parts storage, usable life, moving parts, storage space, etc.	Cyplik P, et al.(2009) Frazzon EM.,et al.(2013) Horenbeek A.Van, et al. (2013) Zanjani MK, Nourelfath M.,(2014) Gan S.,et al.(2015) Kader B.,et al.(2015) Hwang J.Q., Samat H.A.(2019) Dellagi S.,et al.(2020) Yan T., et al. (2020) Zhang S., et al. (2021) Zhang L., et al. (2022) Shirinfar M., et al.(2022)
6		Optimization models for multi-echelon inventory, and Spare parts distribution system	Deployment inventory at various locations based on need, criticality, service response, etc., availability due to location transfers, supply chain, and geographical distribution.	Lau HC.,et al.(2006) Costantino F,et al.(2013) Mohd-Lair N.A.,et al.(2013) Ruan M,et al.(2017) Wen M., et al.(2017) Wang K., Djurdjanovic D. (2018) Patriarca R., et al.(2019) Wang Y, Shi Q. (2019) Wingerden E.V.,et al.(2019) Coelho D.B.P., et al.(2020) Sheikh-Zadeh A,et al.(2020) Guo Y., et al. (2022)

Table 2.1 Approaches using in Spare parts management (Cont.)

App. No.	Phase of MROs Studies	Theme	Framework, Concept, Methodology	Authors
7		Variety models for reusable parts or combinations with new parts, interchangeable spares	Variety models, or across various stages such as cost analysis, stocking, consumption for part repair, parts return, parts reuse, recycled parts, refurbishing spare, and interchangeability of interchangeable parts.	Tan A.W.K., Kumar A.(2006) Pokharel P., Mutha A.(2009) Boudhar H., et al.(2013) Tahirov N.,et al.(2016) Assadi M.,et al.(2018) Wang Y., Shi Q.(2019) Besbes O., et al.(2020) Mitrofanovs V., et al.(2020) Moini G.,et al.(2022) Sharda S., Mishra S.(2022) Richter JL.,et al.(2023) Turki E.,et al.(2024)
8		Integration with predictive maintenance applications	Accessing part design data, the ability to provide the design change, and part changes based on repair and part substitution in remaining machine useful life, integrated with various testing systems and capable of storing predictive analysis and observational data.	Liu Q.,et al.(2013) Horenbeek AV, Pintelon L.(2014) Nguyen KA.,et al.(2014) Bousdekis A., et al. (2017) Einabadi B.,et al.(2019) Gutsch C.,et al.(2019) Kian R,et al.(2019) Chen C.,et al.(2021) Pater de I., Mitici M.(2021) Gayialis SP.,et al.(2022) Rebaiaia M.L, Ait-Kadi D., (2022) Mitici M.,et al. (2023)
9		Integration with the other applications	Integration with total preventive maintenance programs	Ability to use spare parts (esp., consumable materials) in integration with the preventive maintenance schedules that are tightly integrated with operational programs, service maintenance records, inventory system, product data management systems, and so on.
10		Spare parts management by using the performance metrics	To measure maintenance activities by using performance metrics such as failure rate, MTTR, MTTF, Unplanned maintenance downtime, Availability, and percentage of service cost to monitor the efficiency of the maintenance and service processes. Including spare parts logistics and supply chain management.	Alsyouf I.(2006) Leeuw De S., Beekman L.(2008) Au-Yong CP.,et al.(2016) Dahane M.,et al.(2017) Teixeira C., et al.(2018) Achetoui Z.,et al.(2019) Wakiru JM, et al.(2019) Capodiec A,et al.(2020) Bounou O., et al.(2020) Arifin M.M.,et al.(2023) Zhang M.,et al.(2023) Wang Y.,et al.(2024)
11		Share the best practices	Ability to share the best practices or a case study of standard service practice across the different groups, proposing the best idea, concept, and framework for spare parts or maintenance management. Integrate with the other best applications such as Lean management, Five S, FIFO system, and other good applications for spare parts management.	Bevilacqua M.,et al.(2011) Chen JC,et al.(2013) Ivcekno J., Chaudhuri A.(2017) Andersson J., Jonsson P.(2018) Keivanpour S., Kadi DA.(2019) Stip J. and Houtum GJ Van (2020) Mor RS,et al.(2021) Sufa M.F., Mulyana M.K.(2021) Putra B.P., et al.(2021) Aji S.N., Nindiani A.(2022) Ramezani S., Hoseinzadeh MR.(2022) Zhang C.,et al.(2022)

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Table 2.1 Approaches using in Spare parts management (Cont.)

App. No.	Phase of MROs Studies	Theme	Framework, Concept, Methodology	Authors
12		Spare part expiry, supersession, deterioration, obsolescence (or discontinued spares)	Ability to extend, help maximize usable life, predict part obsolescence, and be superseded by a new part, and the spare parts control balances with the deteriorating inventory.	Torresen J and Lovland TA.(2007) Fera N.,et al.(2010) Schulze S.,et al.(2012) Venkatesan M.(2014) Volkenburg Van C.,et al.(2014) Jiang Y., et al. (2015) Cherukuri MB., Ghosh T.(2016) Shi Z.,(2019) Lin D.,et al.(2020) Zhang J.X, et al. (2020) Li D. and Mishra N.(2021) Pater de I., Mitici M.(2021)
13	Life Cycle Analysis and End of service life	Ability to handle end-of-life, part alternates, and substitution	Ability to capture substitution relationships at the planning level, end-of-life parts inventory control, warranty period spares, and post-product life, including incorporating substitution logic during service execution.	Inderfurth K.,Mukherjee K.(2008) Kim B, Park S.(2008) Ilgin MA, Gupta SM (2009) Kleber R., et al.(2012) Inderfurth K., Kleber R.(2013) Hur M., et al.(2018) Bluett AH ,et al.(2019) Shi Z.,(2019) Leijnse N. (2020) Loftesnes N. (2021) Liu S., et al.(2021) Wakiru J.,et al.(2021)
14		Spare parts based on reliability and life cycle analysis	Ability to analyze the equipment life cycle, lifetime prediction, and reliability under both controllable and uncontrollable situations such as environment, working conditions, humidity, and so on. Spare parts are needed for different conditions.	Käki A.(2007) Carpentieri M., et al.(2007) Smit M.(2009) Bensing L. (2012) Durán O.,et al.(2016) Accorsi R.,et al.(2019) Gaspars-Wieloch H.(2019) Duran O., Afonso PSLP.(2020) Zhang J.X., et al.(2020) Cardeal G.,et al.(2021) Macedo L., et al. (2022) Zheng J., et al. (2023)

Again, this study collected related works by looking at research articles, related academic books, textbooks, and information from various websites related to the study of spare parts. The primary platforms for locating articles include Google Scholar, and ResearchGate, and the data spans from 2004 to 2024, with a limited inclusion of earlier years. Then the said information was collected and summarized as in the table shown earlier.

Regarding to this study, focusing specifically on the study group on inventory management (not only spare parts but to include all materials). A lot of research has been conducted in various forms to find an appropriate inventory policy. Through the verifying of earlier research studies and a thorough review of pertinent documents, it has been identified that prior research articles can be categorized into two primary groups related to finding the arithmetic and equations used for determining the appropriate amount of inventory storage:

Group 1 is Classify-Based Inventory Management: This consists of the following sub-approaches as.

- ABC Analysis
- VED Analysis (used in production process)
- VED Analysis (used in healthcare and pharmaceutical industries)
- XYZ Analysis
- FSN (or FNSD) Analysis
- HML Analysis
- SDE Analysis
- SOS Analysis
- GOLF Analysis

The classification employed by this group involves categorizing materials based on the Pareto principle, with a general breakdown into three subgroups distributed in the ratio of 70:20:10. The subsequent section will provide a detailed explanation of each classification.

Group 2 is Formula-Based Inventory Management: This consists of the following sub-approaches as.

- Heuristics:

Heuristics are rule-of-thumb strategies or decision-making approaches that simplify problem-solving. In the context of inventory management, various heuristics are used to make decisions efficiently. Some common heuristics may include:

- EOQ, FOQ, EPQ, EOI Model
- (R, s, Q) Model
- Newsvendor (or Newsboy) Model

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- Least Unit Cost Heuristics
- Silver-Meal Heuristics
- Min-Max Policy
- Base Stock Policy
- Critical Ratio Policy

- Algorithms:

An algorithm for inventory management refers to a step-by-step set of rules or procedures designed to guide decision-making in handling and controlling a manufacturer's inventory. These algorithms are developed to optimize inventory-related processes, ensuring that organizations can meet customer demand while minimizing holding costs, stock outs, and other associated expenses. The primary objective of inventory management algorithms is to strike a balance between maintaining sufficient stock levels to fulfill customer orders and minimizing the costs associated with holding excess inventory. The algorithms may include (Adapted from Tersine, R.J. (1994)):

- Lot-for-Lot Ordering
- Dynamic Lot-Sizing Algorithms
- Wagner-Whitin Algorithm
- Part-Period Algorithm
- Groff's Marginal Cost Algorithm
- Periodic Review System

What makes an algorithm different from heuristics is that an algorithm confirms the optimal point in a given value, whereas heuristics only confirms that the optimal point is in the area or neighborhood that heuristics provides. However, the use of heuristics can be easily understood and used. It's easier to work with than an algorithm because almost algorithms are dynamic programming and require a lot of data to calculate, and the calculation is very complicated. In practical scenarios, numerous types of spare parts are often calculated simultaneously, and users prioritize speed over pinpointing the optimal point because minor variations in spare parts costs do not significantly impact the overall expenses. Occasionally, calculating the optimal cost savings at 100% may not be essential, given the volume of data and the intricacy of the process. Moreover, it is crucial to recognize that algorithmic approaches may not usually provide answers to questions and problems, particularly in scenarios involving probability or stochastic elements.

Ultimately, all of the above are principles and concepts that can be traced in this study and at this present (or may probably have more) which are the forms of mathematics or formulas used to find the appropriate inventory can be found in related articles and research, including academic books about inventory systems in warehouses. This can be summarized in Figure 1.

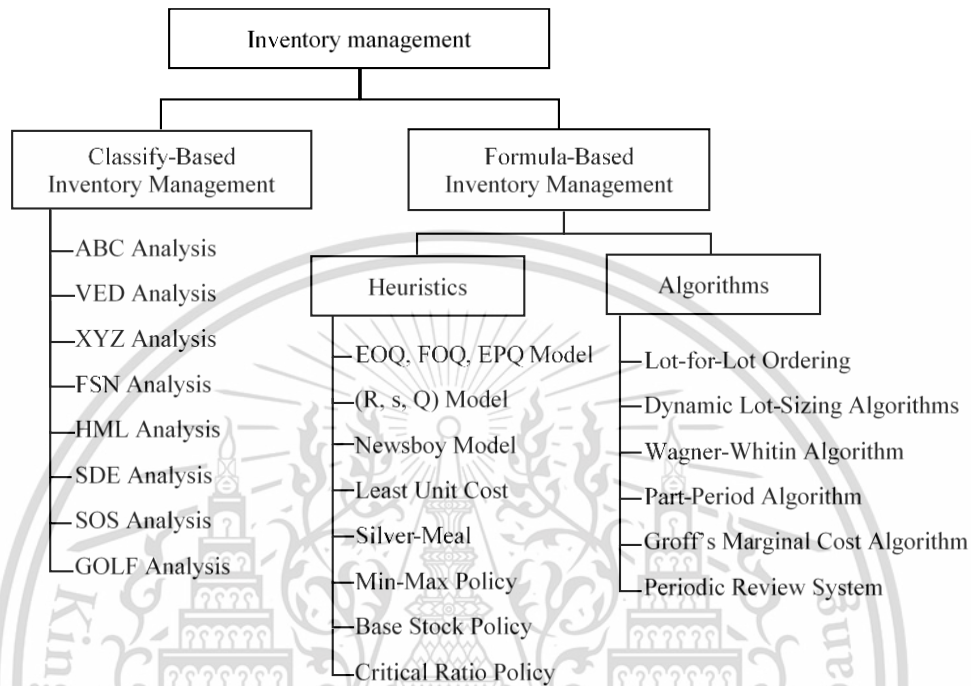


Figure 2.1 Summary of approaches using to find the inventory level (Arithmetic approach)

According to previous paragraph, the details mentioned in previous paragraph may not include methods to find or other methods involved in determining this large material inventory, or it is in a management format rather than a quantifying method such as MRP, ERP, Kanban system, Two-Bin system, Just-In-Time (JIT), Push-Pull system, Periodic Inventory System, Vender Managed Inventory, and so on. The mentioned methods are not approach using to calculate amount of materials inventory but it is an inventory process, inventory planning, materials inventory management or inventory process rather than a method for quantifying orders. Or a mathematical model (or formulas) is used for finding the inventory policy, or it is exploited to determine the number of materials at any given time. In simpler terms, these are administrative protocols and not methodologies for inventory quantification; hence, they are not addressed or considered in this study.

Conclusively for this section, almost of the articles and research studies for Group 1 (Classify-Based Inventory Management) is arranged in approach No.3 (Spare parts inventory based on classification analysis), while Group 2 (Formula-Based Inventory Management) is

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arranged in approach No.4 (Spare parts analysis based on service levels, lead time and parts consumption). The grouping and guidelines described above are to facilitate the review of related documents in order to determine the scope of the study and the number of documents to be reviewed and verified due to the large number of articles that have been studied and published work. Therefore, categorizing, framing in, and dividing into groups is probably the ideal approach.

Initially, it is essential to grasp the principles of spare parts classification the categorization of spare parts across various related criteria. These principles exist in diverse forms and play a crucial role in comprehending the present research investigation. The research itself is conducted based on distinct groups of spare parts. This literatures review of relevant documents can reveal eight fundamental types of classified methods as:

1. ABC analysis, also known as Pareto analysis or the ABC classification, is a technique used in inventory management and resource allocation to categorize items based on their importance or value. The name "ABC" comes from the three categories used in the analysis: A, B, and C. Here's how the classification typically works:

- Category A (High Value, Low Volume): This category includes items that contribute significantly to the overall value of the inventory but represent a relatively small percentage of the total items in stock. These items are often critical to the business, and careful attention is needed to manage them effectively.
- Category B (Moderate Value, Moderate Volume): Items in this category have a moderate impact on the overall value of the inventory. They are neither as critical as Category A items nor as numerous as Category C items. Managing these items involves a balanced approach.
- Category C (Low Value, High Volume): This category comprises items that individually contribute little to the overall value of the inventory, but collectively they make up a significant portion of the total items in stock. These items are often less critical, and less attention is typically devoted to their management.

The aim of ABC analysis is to help organizations prioritize their efforts and resources by focusing more attention on the items that have a higher impact on the overall performance and profitability. By classifying items into these categories, businesses can implement different inventory management strategies for each group. For example, more rigorous control and monitoring may be applied to Category A items, while Category C items may be managed with more relaxed controls. ABC analysis is widely used in supply chain management, inventory control, and procurement to optimize decision-making and resource allocation.

2. VED analysis is another inventory management technique that classifies items based on their criticality and the potential impact of their shortage on production system. The acronym VED stands for Vital, Essential, and Desirable. This classification helps in determining the level of control and attention that should be applied to different items in the inventory. Here's how the classifications are typically used:

- Vital (V): Strict control and monitoring are applied to vital items. Organizations may keep higher safety stock levels, implement rigorous quality control, and have contingency plans to ensure the availability of these critical items.
- Essential (E): Essential items require a moderate level of control. Inventory policies for essential items are less stringent compared to vital items, but they still warrant attention and regular monitoring.
- Desirable (D): Desirable items are managed with a more relaxed operation. Manufacturers may have lower safety stock levels and less frequent monitoring for these items.

VED analysis, combined with other inventory management techniques like ABC analysis, helps organizations optimize their inventory control strategies based on the criticality of items and their impact on overall operations in prioritizing resources and efforts for inventory management.

As mentioned in previous paragraph, VED analysis is used in two cases: in the healthcare (and pharmaceutical industries), and the production process. The difference is in the importance of Vital in the healthcare industry meaning that it is important to human health. As for the importance of Vital in the meaning of production process, it is important to the machine where is at the critical point of the system. It has a completely different meaning. Therefore, the usage is different. For this research, VED analysis in the health department and pharmaceutical industries will not be considered because they are not related.

3. XYZ analysis is another inventory management technique used to classify items based on their demand variability and predictability. Similar to ABC analysis, XYZ analysis helps organizations to prioritize their inventory management efforts but focuses on forecasting and demand patterns rather than item value. The three categories in XYZ analysis are X, Y, and Z, representing high, medium, and low demand variability, respectively. It can be classified as:

- X Category (High Variability): Items in the X have high demand variability, meaning their demand is unpredictable. These items may experience fluctuating demand patterns, making it challenging to forecast accurately. As a result, close monitoring and agile inventory management practices are often required for items in this category.

- **Y Category (Moderate Variability):** Items in the Y category have a moderate level of demand variability. While not as unpredictable as Category X items, they still require careful monitoring and a more balanced approach to inventory management. Organizations typically use standard forecasting methods for items in this category.
- **Z Category (Low Variability):** Items in the Z includes items with low demand variability, or demand is stable. These items have a more stable and predictable demand pattern, making it easier to forecast accurately. Organizations may use simpler forecasting methods for items in this category, and inventory management practices can be less intensive compared to Categories X and Y.

XYZ analysis is particularly useful in guiding organizations to apply different inventory management strategies based on the nature of demand for each item. For example: X items: These are often managed with a more responsive and dynamic approach, with frequent adjustments to inventory levels based on real-time demand changes, Y items: A more balanced approach to inventory management is suitable, with periodic reviews and adjustments to account for moderate demand variations, Z items: These items can be managed with a more routine and stable approach, with less frequent reviews and adjustments due to their predictable demand patterns. By categorizing items into X, Y, and Z based on demand variability, organizations can tailor their inventory management strategies to better match the characteristics of each item, optimizing the balance between service levels and inventory costs.

4. FSN analysis is another inventory management technique that classifies items based on their usage patterns within a specific timeframe. The acronym FSN stands for "Fast-moving, Slow-moving, and Non-moving" items. (Or sometime, this analysis also has D that refers to Dead items, this is not an important matter that must be taken into consideration). This analysis helps organizations in managing their inventory efficiently by categorizing items according to the consumption rates. The FSN can be classified as:

- **Fast-Moving (F) Items:** These are items that have a high consumption rate or turnover. Fast-moving items are frequently in demand and have a quick sales cycle. Organizations often prioritize efficient restocking and close monitoring for these items to ensure that they are readily available to meet customer demand.
- **Slow-Moving (S) Items:** Slow-moving items have a lower consumption rate or turnover compared to fast-moving items. They are not in high demand, and their sales cycle may be more extended. Organizations typically manage these items with more caution, optimizing the inventory levels to avoid overstocking while ensuring that they are available when needed.
- **Non-Moving (N) Items:** Non-moving items are those that have not been consumed or sold within a specific timeframe. These items may be obsolete, have low demand,

or face other challenges in terms of market acceptance. Managing non-moving items efficiently is crucial to avoid tying up valuable resources in stagnant inventory.

FSN Analysis helps businesses make informed decisions about inventory stocking levels, order quantities, and overall inventory management strategies. By categorizing items based on their movement patterns, organizations can allocate resources more effectively, minimize carrying costs, and improve overall inventory turnover.

5. HML analysis is a tool used in inventory management to help classify inventory items and inventory control. This is an inventory method that categorizes inventory based on a product's unit price. The classification gives an idea by its name. H, M, and L stands for high, medium, and low, respectively. This method classifies inventory into the following categories:

- (H) High Cost: Includes high unit value/cost products. Normally they are 10-15% of the total items.
- (M) Medium Cost: Includes average or medium unit value items. 20-25% of products fall into this category.
- (L) Low Cost: Includes items with low unit value. 60-70% of the products are usually low-cost.

HML analysis, this method is very similar to the ABC analysis method, but ABC uses a material value classification (volume times price per unit), but this method uses only the price per unit of material to classify materials. This method enables businesses to allocate resources more effectively for inventory-related activities. By identifying the items that require the most attention, businesses can prioritize stock verification efforts, safety stock levels, and procurement strategies. This optimization of resources ensures that critical items are adequately managed while minimizing the effort spent on low-value items.

6. SDE analysis, this is an acronym for Scarce, Difficult, and Easy, is a simple yet effective inventory classification technique that helps businesses categorize their inventory items based on their availability, procurement complexity, storage, and replenishment strategies. By classifying the goods as following:

- Scarce (S) Items: are characterized by limited supply, long lead times, and potential disruptions in procurement. These items often require specialized manufacturing processes, import restrictions, or sourcing from remote locations. Businesses should prioritize procurement of scarce items to avoid stock outs and ensure continuous production or service delivery.
- Difficult (D) Items: are readily available domestically but may pose procurement challenges due to limited suppliers, transportation constraints, or complex quality

control requirements. These items require careful monitoring and proactive procurement strategies to prevent stock outs.

- Easy (E) Items: are characterized by readily available, locally sourced, and easily procured inventory. These items typically have multiple suppliers, short lead times, and relatively stable demand patterns. Businesses can focus on maintaining optimal stock levels for easy items.

SDE analysis guides inventory decisions, ensuring that appropriate safety stock levels are maintained for each category of items. Scarce items, with their potential for stock outs, require higher safety stock levels to buffer against supply disruptions. Difficult items, while less susceptible to stock outs, still need sufficient safety stock to accommodate potential delays or quality issues. Easy items, with their readily available nature, can be managed with lower safety stock levels, minimizing carrying costs.

7. SOS analysis (or Seasonal analysis) is grouping according to season. Commonly used in warehouse management work to be able to manage and prepare the treasury in accordance with seasonal variations abilities that vary with the seasons. It can be clearly defined and divided into two main groups: in-season (Seasonality) and out-of-season (Off Seasonality), which will be used both in part of the distributor (Supply) and in part of the customer (Demand). Seasonal variations if managed great deal. It will help in arranging raw materials for production, proper inventory and distribution management. SOS analysis can be selected when we want to determine the seasonality of products and the appropriate season for sourcing those products. Example analysis in this section:

- Seasonality of suppliers (or Supply) such as agricultural product groups with a clear period of time issued; how much and how little will vary according to the season.
- Seasonality of customers (or Demand) such as school uniforms will have a lot of sales during the school term or equipment that has a sales period only in the beginning of April, etc.

Seasonal management, it is used to identify items that can be procured and used. They are only available for a limited time each year. And there is a period of time that returns to a certain amount every year like as fruits (such durian, pineapple, and mango) which are only available in abundance during the summer season. If gardeners want to plan to store raw materials in order to have enough to use. Specifying seasonal items will incur costs. It is different from the design to be ready for use all year round. And the costs associated with managing something off-season are often quite high. Dealing with out-of-season items. There are many ways to manage inventory control with respect to seasonality. In using each method, the main focus is on the method that is appropriate for the desired purpose, and to carry out seasonal inventory control.

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8. GOLF analysis, which stands for Government Supply, Ordinarily Available, Local Availability, and Foreign Source of Supply, offers a systematic framework for classifying inventory. This framework allows businesses to enhance procurement strategies, streamline inventory procedures, and reduce costs. This analysis gets its name from categorizing inventory items into four main groups as:

- G (Government Supply): Inventory items acquired directly from government agencies or authorized suppliers.
- O (Ordinarily Available): Inventory items easily accessible from various suppliers, often at competitive prices.
- L (Local Availability): Inventory items obtained from local suppliers, providing benefits such as lower transportation costs and quicker delivery times.
- F (Foreign Source of Supply): Inventory items acquired from international suppliers, usually motivated by cost savings or access to specialized products.

GOLF analysis proves to be a beneficial instrument for companies aiming to refine their inventory management procedures and attain operational efficiency. Through the categorization of inventory items according to their sources of procurement, businesses can refine their procurement strategies, lower holding costs, and mitigate supply disruptions. Additionally, GOLF analysis plays a role in strengthening supplier relationships, simplifying inventory processes, and increasing transparency in the supply chain.

According to GOLF analysis, this can be applied to spare parts inventory management. Previous research and studies that can trace found that no studies have been conducted and can be classified into four types according to the division of original GOLF analysis. However, it can be found some studies that classify spare parts inventory into spare parts produced within the country (local suppliers or domestic) and abroad (international suppliers or foreign). As a result, it is suggested that research on this particular classification of spare parts can be divided into two primary groups, as mentioned earlier.

To explain up to this point, it must be summarized how the guidelines related to the classification methods mentioned above are formatted so that those who will use this information can understand it. How is it used? And are there various articles and related research that refer to, or use methods of classifying, or classifying materials in what form to manage the inventory? This summary is to make it easier to understand as table 2.2.

Table 2.2 Summary of materials classification methods

Class No.	Classify Method	Category	Criteria	Application	Apply to spare parts inventory management	Authors
1	ABC analysis	- A: High value, Low volume - B: Moderate value, Moderate volume - C: Low value, High volume	Classify according to material value (unit cost x volume)	Determine how many amount of valuable materials should be stored	Amount of parts stored depending on value.	Mohita G.S., and Kashi N.S. (2014) Fernanda O., and Clara B.V. (2015) Rajest H., and Vivak A.S. (2019)
2	VED analysis	- V: Vital items - E: Essential items - D: Diserable tiems	Classify according to an importance to production or importance to the machine	Determine the amount of materials stored by an importance to production	Amount of parts stored by criticality to the machine or system	Mohammad A., et al. (2017) Puspitasari A.S., et al. (2019) Bayu P.P., et al. (2021)
3	XYZ analysis	- X: High demand variability - Y: Moderate demand variability - Z: Low demand variability	Classify according to demand variability.	Determine the amount of materials by the variability of demand.	The amount spares stored by the stability of the need for use	Prakash T., and Ramesh K. (2016) Wisam Al-D., Walid E. (2020) Rahul S.M., et al. (2021)
4	FSN analysis	- F: Fast moving items - S: Slow moving items - N: Non-moving items	Classify according to movement of uses	Determine the amount according to the speed of uses.	Amount of spares stored by usage speed	Shibamay M, et al. (2015) Catarina T., et al. (2017) Rahul S.M., et al. (2021)
5	HML analysis	- H: High cost items - M: Medium cost items - L: Low cost items	Classify according to unit price	Determine how many amount of cheap and expensive materials should be stored	The amount of storage for cheap and expensive spare parts.	Pragati J., and Maheshwar J. (2020) Mekete A.D., and Belete S.Y. (2021)
6	SDE analysis	- S: Scarce Items - D: Difficult Items - E: Easy Items	Classify according to difficulty of obtaining materials or difficulty of ordering.	Determine the amount of materials depending on difficulty of acquisition and based on aviability.	The amount storage depends on the difficulty of ordering parts.	Vivek A.D. (2008) MarichelvamM.K., et al. (2017)
7	SOS analysis	- Seasonality of suppliers (Supply) - Season of customer (Demand)	Classify according to seasonality, or In-season and Out-of season	Determine amount of materials depending on seasonal quantities	Cannot apply to spare parts management	Not Applicable
8	GOLF analysis	- G: Government Supply - O: Ordinarily Available - L: Local Availability - F: Foreign Source of Supply	Classify according to source of materials	Determine amount of materials depending on source of acquisition	For this case can classify spare parts to be Foreign and Domestic supply	José R.R., and Marco A.M. (2015) Xiaoqing W. (2019) Monica M., and Sehgal S.C. (2023)

Hence, what about this research study? What does it do that is different from the previous works? What are some of the things that stand out that make the study more interesting than the previous ones? Is there anything that can be said that is new? Is anything presented as being significantly better than previous studies? And what is the contribution to knowledge? How can these questions be answered because they are so difficult to answer? These questions are both very intriguing and challenging.

To answer this question requires first understanding that the important thing is to understand how the need for spare parts arises. Of course, the first importance, it is to look into previous research to see what work has been done on this case. And discovered that there are quite a few previous studies that have studied this issue, such as Hasni M., et al. (2019), Auweraer S.V. (2019), Hemeimat R., et al. (2016), and so on. Whenever you check and look at the details of those studies, you will find that previous studies used a continuous pattern of failure, whether it be a normal distribution, an exponential distribution, or a Weibull distribution. Especially, these types of distributions are often popularly used to analyze the causes of breakdowns or the need for spare parts, such as Ali J.B., et al. (2015), Yongquan S., et al. (2016), Fragassa C. (2024), and so on. Indeed, there are some studies like Patriarca R., et al. (2019) that applied the Weibull distribution in a discrete pattern format, but it doesn't seem to follow the nature of this type of statistics and it still looks a bit forced. There are some conflicts but it's a good idea, be applied quite wonderfully, and be a strange concept in application. However, the author believes that discrete statistics must be used in the form of discrete failures (or intermittence pattern).

In real life, there is probably no machine or system that will always be failures or can fail every day. There may be cases where major repairs or overhauls to such machines or systems may have to be made because they are continually broken. Therefore, if we are talking about the breakdown of any machine or system, it should be considered in the form of a continuous or discrete breakdown. The author believes that it would be more appropriate to use a discrete pattern such as Binomial or Poisson to analyze is more appropriate. Details of the analysis will be presented in the following theoretical concepts section. However, it is not that continuous statistics cannot be used. In the case that a system has many machines in the system or it's a large system. Or it is the management of spare parts inventory with many sub-centers such as the central spare parts warehouse of an automobile repair center, the main spare parts warehouse for many electrical substations, electric train maintenance centers, large airport, etc. In such cases, it can create demand for the same type of spare parts every day or continuous use of spare parts. The theoretical concepts will be explained in more detail in the next section.

As for this study, what makes a significant difference in spare parts demand from previous studies is to use of binomial or Poisson statics to analyze and study, a review of documents found some such as Costantino F., et al. (2018), Turrini L., Meissner J. (2019), etc., These studies were concerned in spare parts demand with using discrete pattern statistics but no previous study has investigated and verified the connection between discrete and continuous statistics. For example, in the case of using spare parts for a system with a small number of machines compared to a highly complex system with many machines or a center that stores spare parts that must be provided too many sub-centers. So, what is the process of using the Central Limit Theorem or applying it in research? Of course, there has never been a study of this kind before. This study will demonstrate that connection. Including finding the number of spare parts that need to be used to understand the context of machine breakdowns in the system, both large and small.

Particularly, this is to find inventory principles based on the EOQ model that has the characteristics of the probabilistic pattern, it is a discrete pattern rather than a continuous pattern and its safety stock. Previously, almost of all studies looking at demand on lead-time have used normal distribution statistics such as Sato Y., and Jauhari W.A.(2019), Rammner M.(2021), Sen E.G. (2023), which may not be suitable for some pieces of equipment with a failure rate is very little or very scarcely breakdown. In this case, are you still sure that normal distribution statistics are still fully usable? Or if some pieces of equipment are in very important places, can the EOQ model tell you that special care must be taken in determining the appropriate number of such pieces of equipment based on their importance in the machine? There are few or no past studies. Or maybe there is, but it may not be found because the number of studies on this subject is so small that it is impossible to tendency search it cannot be found, that can directly indicate how important this equipment (or part) is to the system. But studies can directly quantify the amount of damage in term of monetary and opportunity cost. And the most important point is when it will be possible to tell if the equipment or parts to be replaced are cheap or expensive. Has there been any research or study in the past that can tell whether it is cheap or expensive? From reviewing and searching for information, it was still found that there was no study or research that clearly stated or stated whether the parts were classified as cheap or expensive. HML analysis appears to be the closest to breaking down the unit price level but this analysis can only tell you whether they fall into expensive, medium and cheap categories. It's just sorted and grouped. There is no dividing line between what is cheap and what is expensive. Suppose that if there are a large number of spare parts, such as those required for large airports, electric trains that have a maintenance center in one place, etc., that need to be arranged in order, how difficult it would be to manage such a large number of parts like that.

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For ordering spare parts and managing spare parts inventory appropriately, another suitable ordering is based on the total quantity of faulty parts, known as Lot-for-Lot ordering. In this method, parts are ordered when machinery breaks down. This method is commonly used when there is a very low or infrequent chance of machinery breakdown. According to the literature reviews, there is minimal interest in studying this approach because this method is not very complex. Typically, this ordering method is applied more to Manufacturing Resource Planning (MRP) systems for production (e.g., Rees L.P., et al. (1989), and Alwan L.C., et al. (2008)) rather than for applied studying the spare parts ordering. This is because, as mentioned above, the ordering pattern is based on the occurrence of failures and the quantity has been ordered equal to the amount lost. In such cases, if machinery breakdowns occur infrequently, thus the ordering cost of spare parts would be much higher than the holding cost in a large quantity and keeping it in stock (in which case there would be holding costs). Therefore, the Economic Order Quantity (EOQ) Model concept is more commonly applied than Lot-for-Lot ordering. However, there are still studies working in this direction. For example, Wongmongkolrit S. and Rassameethes B. (2011) conducted research comparing Lot-for-Lot (LFL) ordering and the EOQ Model. For consideration in this study, the approaches mentioned above will be applied further.

In addition, this study is organized in approach No. 3 and No. 4, emphasizing the grouping of spare parts into different types of spare parts according to related characteristics, namely price per unit, movement of spare parts use, and is important or a spare part that is a critical point in the machine. Once the groups have been divided, the divided parts are put into the appropriate mathematical model. In which the study will apply the EOQ Model. This conceptual framework has the basic concept of thinking to create the most cost savings. Of course, using a single EOQ model to calculate all spare parts inventory will inevitably have gaps that cause costs to still not be the lowest cost. Separating first and then calculating each group according to the appropriate EOQ approach is probably a method that is expected to be better than the traditional calculation method. There will be mathematical proof that this approach can actually be more cost-effective. Answering questions in the traditional way is probably not a good approach. The demonstration and proof will be what makes this will tell why this study is stand out.

Resume back to the details, when compared with Table 2.2, this study falls into the subgroup of material classification methods number 2, 4, and 5, which means VED, FSN, and HML analysis. But this spare parts group will be divided into two scales. It will not be divided into three scales, similar to the classification that mentioned here. This research study predominantly examines pertinent documents from diverse articles within Group 1,

emphasizing Classify-Based Inventory Management. In contrast, Group 2, which centers on Formula-Based Inventory Management, specifically reviews studies related to the EOQ Model. Given that this study excludes Heuristics and Algorithms or the other methods, there is no requirement to delve into literature and research in these specific domains. The forthcoming paragraph will provide detailed information on the document review and related research.

Consequently, this study may suggest that there are many new developments that apply innovative imagination and revolution in thinking in the management and inventory control of spare parts, without being heavily tied to traditional thought processes. Traditional thinking does not attempt to integrate comprehensive ideas or consider a synthesis of ideas between two or three approaches. But there are numerous studies that have implemented a combination of ideas from the third and fourth approaches, such as Hanafi R., et al. (2019), Al-dulaime W. and Emar W. (2020), Emar W., et al. (2021), and many more. However, upon closer reviewing and verifying of the content, it is evident that it is not a fusion of ideas but rather a method of comparing the inventory methods of two approaches to determine which one is superior, more than they are integrated seamlessly with together.

Conclusively, from the preceding paragraphs that have been presented all of this. The author can summarize how previous studies compare with this study what is there any difference and what can the knowledge be added from this study. They are summarized in Table 2.3. This table will show the issues of summarization of how this study differs from previous ones (or can summarize as the previous research gaps), with the stand out of significant understanding being the spare parts inventory control study. The most important point is determining what exactly makes this study the contribution to knowledge. And, there can be no further argument that it would be useful to fulfill the niche and gaps in past studies for finding better and more reliable for spare parts inventory management.

Table 2.3 Summarize of this study differs from previous ones

Issues consideration		Previous studies	This study	Significant Contribution to Knowledge
Spare parts demand	Pattern	Continuous or Discrete only	Combine between Discrete and Continuous	Integrated component study not divided, Real life happens like this.
	Point connection	No clue	Thinking on the basis of Central Limit Theorem	The practical and logical application of theory is the result, and connect between discrete and continuous pattern.
Classify method	Selection of classify method	Individual selection and View gaps from previous studies	Choose from suitability for actual use.	It is a study based on actual use rather than from looking at or finding gaps from previous studies. When put into actual use, it makes more
	Scale of classification	Three scales (High, Middle, and Low)	Two scales (High and Low)	In actual use with middle-scale spare parts management, this is not realistic and is difficult to
	Relationship between each selected method	They are related together, but they are related studies that have an end in which the combination of methods is not used on further and not to be used on next step.	There is a related with together in complete harmony and correspond between each classification method that does not have an end but must continue to be used on further and in next step.	It opens up a new approach to the study, have a new point of view, more than any study that has no connection points.
Finding the amount of inventory, and number of spares	Method selection	Selected based on the appropriateness of each author who has examined gaps in previous studies	Choose from gaps in theory when it comes to practical applications, especially for systems with high complexity and a large number of spare parts usage.	A truly suitable method has been devised to determine the appropriate quantity of spare parts based on usage speed, price, and vital.
	Safety stock calculation	Almost all of them use continuous statistics in their thinking.	Not every case. If failures a little, apply discrete statistics. If fail continuously, apply continuous statistics, which seems more reasonable.	For the first time, discrete statistics will be applied to account for spare parts lead times.
	Putting it into practice	It is practical, but it is a problem that focuses on a specific group and cannot be used to solve holistic problems, especially for large systems with high complexity. Or if it can be used, it takes a lot of time and uses a lot of data.	Thinking on the basis of actual use and solves problems that arise from actual case. When put into actual use, it will be easier to use, uses less data. It's more convenient, especially for large systems that use a lot of spare parts.	This study is thought on the basis of actual problems. Of course, when it comes to actual use, it's easier and more realistic.

Once again, this summary table serves as an indicator of how the proposed approach is superior to the traditional one. It highlights the differences, emphasizes its importance in the study, and outlines the benefits it brings to spare parts management. The most crucial aspect of this innovative thinking method, not being tied to traditional ideas, is the rebellion against traditional research concepts, and it cannot be argued that it represents a revolution in thought. This material is reserved for educational use only, not allowed for commercial use.

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THEORETICAL CONCEPTS

The arising of spare parts uses (Demand)

Initially, one should take into account the comprehension of component failure along with its variability concerning the reliability function. The subsequent examples introduce the foundational concept of spare parts demand or the requirement for spares.

2.1 Component failures

The occurrence of a breakdown is an event in the form of probabilities that cannot be predicted. However, the failure of parts in a machine or system has an average of failures and an average of the time interval between each failure. When considering the failure of devices in a machine, it is necessary to take relevant statistics into consideration as follows.

1. Binomial distribution

The need for spare parts arises exclusively from the breakdowns of a machine's parts (or components, devices, elements). Consequently, instances of failures are identified as the demand for spare parts. The initial approach to calculating spare parts demand involves employing the Binomial distribution. The concept revolves around determining whether a part fails; if a failure occurs, the part must be replaced.

Refer to Montgomery and Runger (2011), The random variable X that equals the number of trials that result in a success has a binomial random variable with parameters $0 < p < 1$, and $n = 1, 2, \dots$. So, the probability mass function of X is:

$$f(x) = \binom{n}{x} p^x (1-p)^{(n-x)} \quad (1)$$

With mean: $\mu = E[X] = np$ (2)

And variance: $\sigma^2 = V[X] = np(1-p)$ (3)

Where: p = probability of success (or probability of failure).

x = number of success (or number of failures), and $x = 0, 1, \dots, n$

A widely used distribution emerges as the number of trials in a binomial experiment increases to infinity while the mean of the distribution remains constant.

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Recall to equation (2): $E[X=x] = np$ and suppose equal to λ or $E[X] = np = \lambda$.

$$\text{Then: } P(X = x) = \binom{n}{x} p^x (1-p)^{n-x} = \binom{n}{x} \left(\frac{\lambda}{n}\right)^x \left(1 - \frac{\lambda}{n}\right)^{n-x} \quad (4)$$

Suppose that the number of failures (n) increases and the probability of the failures decreases exactly enough that pn remains equal to a constant, such that $E[X] = \lambda$. Remains constant. Then, with some work, it can be shown that:

$$\text{Term: } \binom{n}{x} \left(\frac{\lambda}{n}\right)^x \rightarrow \left(\frac{1}{x!}\right)$$

$$\text{Term: } \left(1 - \frac{\lambda}{n}\right)^{-x} \rightarrow 1$$

$$\text{And: } \left(1 - \frac{\lambda}{n}\right)^n \rightarrow e^{-\lambda}$$

So that:

$$\lim_{n \rightarrow \infty} P(X = x) = \frac{e^{-\lambda} \lambda^x}{x!}, \quad x = 0, 1, 2, 3, \dots$$

Because the number of devices in the machine or system tends to infinity, the number of components failure can equal any nonnegative integer. Therefore, the range of X is the integer from zero to infinity.

2. Poisson distribution

Adapted from Montgomery and Runger (2011), this can be described when the random variable X that equals the number of count (or failure occurrences) in the interval is a Poisson random variable with parameter $\lambda > 0$ (where λ is represented components failure rate), thus the probability mass function of X is:

$$P(X = x) = \frac{e^{-\lambda} \lambda^x}{x!} \quad (5)$$

And the cumulative distribution function of Poisson is:

$$P(X \leq x) = \sum_{i=0}^x \frac{e^{-\lambda} \lambda^i}{i!} \quad (6)$$

$$\text{With mean: } \mu = E[X] = \lambda \quad (7)$$

$$\text{And variance: } \sigma^2 = V[X] = \lambda \quad (8)$$

Regarding to equation (5), variable x is the number of occurrences of an event. The x value is represented the event of failure occurrences. The Poisson distribution can be easily formed by using the Poisson statistical table rather than calculates by using equation (5).

3. Normal distribution approximation to Poisson distribution

According to Montgomery and Runger (2011), Practical Interpretation: Poisson probabilities that are difficult to exactly compute and can be approximated with easy-to-compute probabilities based on the normal distribution. Thus, the Poisson distribution is also not suitably applied with frequent machine breakdowns during an observed period. This is because calculating the cumulative density function for this type of distribution is rather difficult. So, the normal distribution with the central limit theorem shall be exploited.

Montgomery and Runger (2011) described that the correction factor is used to improve the approximation. However, if np or $n(1-p)$ is small, the binomial distribution is quite skewed and the symmetric normal distribution is not a good approximation. The normal distribution can be used to approximate binomial probabilities for cases in which n is large. The approximation is good for $np > 5$ and $n(1-p) > 5$. The Poisson is approximately a standard normal random variable. The same continuity correction used for the binomial distribution can also be applied. The approximation is good for $\lambda > 5$ during an observed period.

However, the Poisson distribution is completely defined by intermittent demand. The standard deviation of the Poisson distribution is the square root of its mean (or variance is equal to the mean). So, knowledge of the average demand is sufficient to describe this distribution. The Poisson distribution is not suitably applicable to distributions with a mean value above five. Only slow-moving items are commonly well-described by this distribution. There are instances where demand is sporadic, discontinuous, and not symmetrical.

If X is a Poisson random variable with mean is $E(X) = \lambda$ and variance is $V(X) = \lambda$, then the Normal distribution can be used to approximate the probabilities of a Poisson distribution: The general form of normal distribution, the Z value is:

$$z = \frac{X - \mu}{\sigma}$$

Then, transform to be:

$$Z = \frac{X - \lambda}{\sqrt{\lambda}} \quad (9)$$

$$\text{So: } P(X \leq x) = P\left(Z \leq \frac{x-\lambda}{\sqrt{\lambda}}\right) \quad (10)$$

Recall to equation (6), the cumulative distribution function of Poisson is very difficult to compute when demand is over than 20 units on an observed period. Thus, the Normal approximation to Poisson in equation (10) is easier than equation (6) but there is some error of this approximation. So, the sensitivity will be applied to this study in order to compare between these two values.

4. Exponential Distribution

According to Poisson distribution, a random variable is defined to be the failure occurrences during an observed period. The time between failures (between failure occurrences i^{th} to $i+1^{\text{th}}$) in another random variable that is often of interest. Let the random variable X denotes as time between failure from occurrence i^{th} to $i+1^{\text{th}}$. Generally, let the random variable N denotes as number of failure occurrences. If the mean number of failures is λ per interval observe time. Variable N has a Poisson distribution with mean λx . Therefore, probability of time between failures are longer than the value of x is:

$$P(X > x) = P(N = 0) = \frac{e^{-\lambda x} (\lambda x)^0}{0!} = e^{-\lambda x} \quad (11)$$

The cumulative distribution function of X is:

$$F(x) = P(X \leq x) = 1 - e^{-\lambda x}, x \geq 0 \quad (12)$$

By differentiating $F(x)$, the probability distribution function of X is calculated to be:

$$f(x) = \lambda e^{-\lambda x}, x \geq 0 \quad (13)$$

The random variable X that equals to the time between failures of a Poisson process with mean $\lambda > 0$ is an exponential random variable with parameter λ . The probability distribution function is as an equation (13).

2.2 Mean time between failures

Component failure may occur on anytime, and it is the probabilistic pattern under the exact standard deviation (σ) with average time of failure occurrences or it is called as mean time between failure (M_{TBF}).

Therefore, the mean time between failures (M_{TBF}) can be defined as:

$$M_{TBF} = \int_0^{\infty} t \cdot f(t) d(t) \quad (14)$$

Recall to equation (11), mean between failures can be re-equated as:

$$M_{TBF} = \int_0^{\infty} e^{-\lambda t} d(t) = \frac{e^{-\lambda t}}{-\lambda} \Big|_0^{\infty} = \frac{1}{\lambda} \quad (15)$$

And, the variance (σ^2) is given by:

$$\sigma^2 = \int_{-\infty}^{\infty} (t - \mu)^2 f(t) dt \quad (16)$$

If μ is represented by mean time between failure, then:

$$\begin{aligned} \sigma^2 &= \int_0^{\infty} (t - M_{TBF})^2 f(t) dt = \int_0^{\infty} t^2 f(t) dt - (M_{TBF})^2 \\ \sigma^2 &= \int_0^{\infty} \left(t - \frac{1}{\lambda}\right)^2 \lambda e^{-\lambda t} dt = \frac{1}{\lambda^2} \end{aligned} \quad (17)$$

If the probability density functions are formed by discrete pattern. Therefore, mean time between failures (M_{TBF} of individual component or part) can be formed as:

$$M_{TBF} = \sum_{all-t} t \cdot P(t) \quad (18)$$

And variance of the distribution can be formed as:

$$\sigma^2 = \sum_{all-t} (t - M_{TBF})^2 \cdot P(t) \quad (19)$$

2.3 Demand of spare parts

Regarding the maintenance actions, spare parts consumption (or demand: D) comes from components (installed in the system) failures. It can be measured as the frequency of failure occurrences within an observed period. The average of component failures during an annual period is called the failure rate (λ) and is equal to:

$$D = \lambda = \frac{1}{M_{TBF}} \quad (20)$$

If k components are installed in the system, and all components are identical, independent, and uncorrelated. Then equation (20) can be rewritten as:

$$D = k \cdot \lambda = \frac{k}{M_{TBF}} \quad (21)$$

If λ_S is the failure rate of the system (of k identical components or devices installed in a system), e.g., there are 20 sets of 1.5 kW gear motors installed in a conveyor system, or the automatic barcode reading system has eight reading heads installed in the system, then:

$$D = \lambda_S = k \cdot \lambda = \frac{1}{\theta} \quad (22)$$

Equation (21) calculates by using individual components failure rate, while equation (22) calculates by using system mean time between failures. Both of them can be represented as an annual demand of spare parts. And, system failure rate (λ_S) and mean time between failure (θ) are observed by based on annual period.

In the case where the failure of the system is viewed as one machine, thus there is no need to take the variable of k into account. For example, in the case where we collect statistical data on the failure of a 1 kW motor with 20 sets installed in the system and find that every 30 days there will be one motor broken, there is no need to multiply the value 20 into equation 22.

Suppose m is the number of parts that must be replaced simultaneously, such as when we have to change two cells of batteries at the same time (although only one cell is power empty) or four spark plugs in a car that must be replaced simultaneously, even if only one spark plug is broken. In that case, it is necessary to replace four spark plugs at once, so:

$$D = \lambda_S \cdot m = \frac{m}{\theta} = \lambda \cdot m \cdot k = \frac{m \cdot k}{M_{TBF}} \quad (23)$$

Equation 23 shows the system demand when a failure occurs, or the demand for spare parts when the system fails. This demand is an average over the observed period, not an actual value. Determining the true value requires that the change in the failure factor or the variation be included in the equation. This value (or the variation) is generally calculated using statistical methods. However, using this demand value to calculate the need for spare parts is an appropriate approach because the variation will be accounted for in safety stocks. This will be explained in the next section.

2.4 Safety stock concept

Refer to Tersine (1994), the two of the best known and most widely exploited statistics for describing distributions are the arithmetic mean and the standard deviation. The arithmetic

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mean is a measure of central tendency, while the standard deviation is a measure of dispersion of a distribution. The arithmetic mean \bar{M} (or mean lead time demand) for a continuous distribution is:

$$\bar{M} = \int_0^{\infty} M \cdot f(M) dM \quad (24)$$

For the discrete distribution, the mean lead time demand is:

$$\bar{M} = \sum_{M=0}^{M_{max}} [M \cdot P(M)] \quad (25)$$

Where: \bar{M} is mean demand on lead time in units.

M is demand on lead time in units.

$f(M)$ is probability density function of demand on lead time

$P(M)$ is probability of lead time demand in units.

M_{max} is maximum lead time demand in units.

When the stock-out probability is the first definite integral of the probability density function of demand during lead time from the re-order point to infinity. If the probability density function is continuous, so:

$$P(M > R) = \int_R^{\infty} f(M) dM \quad (26)$$

The expected quantity during lead time is the second definite integral of the probability density function of demand during lead time from the re-order point to infinity, If the probability density function is continuous, so:

$$E(M > R) = \int_R^{\infty} \left(\int_M^{\infty} f(M) dM \right) dM = \int_R^{\infty} (M - R) \cdot f(M) dM \quad (27)$$

If the probability density function is discrete, so:

$$P(M > R) = \sum_{M=R+1}^{M_{max}} P(M) \quad (28)$$

$$\text{And: } E(M > R) = \sum_{M=R+1}^{M_{max}} (M - R) \cdot P(M) \quad (29)$$

Where: R is re-order point in units.

$f(M)$ is probability density function of demand during lead time.

$P(M > R)$ is probability of stock-out.

$E(M > R)$ is expected stock-out in units during lead time.

If component failure is varied corresponding to its variation which is defined to be system failure standard deviation. Thus, safety stock (SS) is:

$$\begin{aligned}
 SS &= \int_0^{\infty} (R - M) \cdot f(M) dM \\
 &= R \int_0^{\infty} f(M) dM - \int_0^{\infty} M \cdot f(M) dM \\
 &= R - \bar{M}
 \end{aligned} \tag{30}$$

Generally, the calculation of safety stock is based on maximum demand on lead time (or maximum failure during lead time) therefore Re-order point (R) will be represented by M_{max} . Or, safety stock is:

Safety Stock = Maximum demand during lead time (in units) – Average demand on lead time (in units)

$$SS = M_{max} - \bar{M} \tag{30}$$

According to Tersine (1994), the service level on frequency of service per order cycle will indicate the probability of not running out of stock during the replenishment lead time. The approach is not concerned with how large the storage is, but with how often it can occur. The service level per order cycle (SL_C) is defined as the fraction of replenishment cycles without depletion of stock:

$$\begin{aligned}
 SL_C &= \frac{1 - \text{Number of cycles with a stock-out}}{\text{Total number of order cycles}} \\
 &= 1 - P(M > R)
 \end{aligned} \tag{31}$$

The term of $P(M > R)$ is the probability of stock-out during lead time or stock-out level (probability) per order cycle. It represents the probability of at least one stock-out during lead time. Or, this is the fraction of lead time periods when demand will exceed the re-order point.

Recall to equation (30), if the safety stock is determined by the acceptant (or required) service level and it can be used for reflection the confident interval to cover the maximum demand during lead time. Or, safety stock can probably be based on lead time demand at an acceptant (or required) service level (M_a) which is subtracted by average lead time demand. So, the safety stock is:

Safety Stock = Lead time demand at acceptance service level (in units) – Average demand on lead time (in units)

$$SS = Ma - \bar{M} \quad (32)$$

Where: $Ma = R$ = lead time demand at accepted service level in unit.

\bar{M} = average demand on lead time in unit.

Equation (32) serves as the formula for determining safety stock based on the desired service level. It represents the universal method for calculating the necessary spare parts, with the service level indicating the assurance level against stock outs for the required parts.

Supposedly, spare parts lead time is constant. If demand is a discrete (intermittent) pattern, the Poisson distribution will be applied, and the safety stock can be referred to in equation (6). This is the probability of a shortage of spare parts. So, the transformation will be:

$$SS = P(X \geq \bar{M}) = 1 - \sum_{i=1}^{\bar{M}} \left[\left(\frac{\lambda_S \cdot L}{i!} \right) e^{-(\lambda_S L)} \right] \quad (33)$$

Or:
$$SS = P(M_a) = \sum \frac{(\lambda_S \cdot L) \cdot e^{-(\lambda_S L)}}{x!} \quad (34)$$

And:
$$\bar{M} = \text{mean} = \lambda_S \cdot L \quad (35)$$

Refer to equation (10), if demand is continuous pattern, the normal distribution will be applied. This is the probability of a shortage of spare parts same as equation (6). So, the transformation will be:

$$SS = P(X \geq x) = 1 - P(X \leq x) = P\left(Z \geq \frac{x - \lambda}{\sqrt{\lambda}}\right) \quad (36)$$

$$P(X) = P\left(Z = \frac{x - \lambda_S L}{\sqrt{\lambda_S L}}\right) \quad (37)$$

The L in an equation (34), and (37) is observed by annual period. Therefore, the value of L is the collected data and must be adjusted to the annual base.

Note: Supposedly, the alphabet φ is the multiplication number of demands during lead time, or it is equal to variable X in equation (34) when demand is discrete, and in equation (37) when demand is continuous.

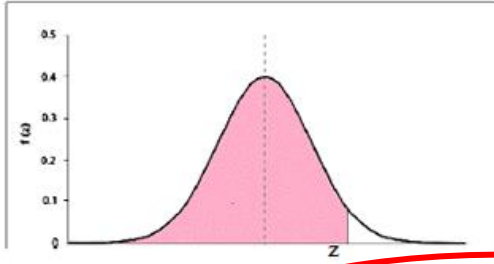
Example, if the required service level is at least 90%, and the failure rate is 4 with the lead time is 6 months, then the required safety stock is:

Table 2.4 Cumulative distribution function of Poisson distribution statistics

$\lambda =$	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
X=0	0.6065	0.3679	0.2231	0.1353	0.0821	0.0498	0.0302	0.0183	0.0111	0.0067
1	0.9098	0.7358	0.5578	0.4060	0.2873	0.1991	0.1359	0.0916	0.0611	0.0404
2	0.9856	0.9197	0.9197	0.8088	0.6767	0.5438	0.4232	0.3208	0.2381	0.1247
3	0.9982	0.9810	0.9344	0.8571	0.7576	0.6472	0.5366	0.4335	0.3423	0.2650
4	0.9998	0.9963	0.9814	0.9473	0.8912	0.8153	0.7254	0.6288	0.5321	0.4405
5	1.0000	0.9994	0.9994	0.9955	0.9834	0.9161	0.8576	0.7851	0.7029	0.6160
6	1.0000	0.9999	0.9991	0.9955	0.9858	0.9665	0.9347	0.8893	0.8311	0.7622
7	1.0000	1.0000	0.9998	0.9989	0.9958	0.9881	0.9733	0.9489	0.9134	0.8666
8	1.0000	1.0000	1.0000	0.9998	0.9989	0.9962	0.9901	0.9786	0.9597	0.9319
9	1.0000	1.0000	1.0000	1.0000	0.9997	0.9989	0.9967	0.9919	0.9829	0.9682
10	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9990	0.9972	0.9933	0.9863

From the above table, the failure rate during lead time is $4 \times (6/12) = 2$ units, and if the required service level is at least 90%, then the required safety stock is 4 units. In this case, the actual value should be determined by the interpolation method between 0.8571 (3 units) and 0.9473 (4 units), and then 3.476 units is the answer.

For example, if using the same problem from the previous paragraph and applying the method of thinking that assumes a continuous cause of failures (assuming failures are the normal distribution), we arrive at the following answer:

Table 2.5 Cumulative distribution function of normal distribution statistics


Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9924	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9958	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986

From the above table, if the required service level is at least 90% and $Z = 1.29$, then the required safety stock (X) is:

$$Z = \frac{X - \lambda_S L}{\sqrt{\lambda_S L}} \rightarrow 1.29 = \frac{X - (4 \cdot 0.5)}{\sqrt{4 \cdot 0.5}}$$

$$X = 3.824 \sim 4 \text{ units}$$

In cases where the failure rate is not more than 5 units, it is more accurate to exploit Poisson statistics, but normal distribution statistics can also be used to estimate this.

Note: Finding safety stocks using statistics with a binomial distribution gives the most accurate values because the analysis of broken machine states (success) and normal machine

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states (non-successful) corresponds to the distribution pattern of this statistic more than any other type. But in practice, finding the probability of a machine breaking down is not easy, and machines with a lot of parts or components have a higher probability of breaking down than machines with a few parts. Therefore, binomial statistics are not a popular way to find safety stock. Collecting data from actual use uses the breakdown rate (failure rate) of machines as a more convenient and easier way to collect data without having to care about whether the machine has many or few components or parts. Therefore, the Poisson statistic is a more suitable alternative.

2.5 Spare parts classification

Theoretically, this research focuses on categorizing the spare parts or maintenance, repair, and operations (MRO), with each category aligning with a suitable inventory model. The inventory management model proposed in this study is conceptualized by distinguishing between high and low conditions based on three primary contributing factors: Necessity, Movement (frequency of use), and Unit cost.

Necessity (or criticality) is an important spare (or part/device) of the system or can be called a critical part. Necessity parts have to be stocked in at least one unit but this is not limited to ensure that part can be in hand at all. Sometimes it has to spare more than one which is dependent on its installation position. This can be separated into 2 classes as much and less necessity. Much necessity is vital to the system if there is some failure then a new part has to be replaced as soon. Contrary, a part can allow being shortage.

Movement (or frequently use) is not the quantity of materials (or parts) used similar to ABC analysis. But movement is the flow of materials or parts usage. Some parts may not be the majority installed components but they may have a little installation in the system but always ever failure or break down. So, movement may reflect the parts usage rather than the quantity used in ABC analysis. Moreover, the medium-term will be taken out cause of is easy to classify the quantity of movement. Therefore, we separate the movement into 2 classes as fast and slow movement. Meaningfully, fast movement is parts that often to be a failure and slow movement is difficult to be a failure. Or, fast-moving items can represent continuous demand, and slow-moving items can represent discrete demand.

Cost is material (or parts/devices) unit price. And, it is not valuable material which is not similar to ABC analysis. Cost factors can be separated into two groups high and low-price spares. High-cost materials can usually be stocked as little as possible, while low-cost materials

(or parts/devices) can probably be plenty stocked to ensure that there are no chances to be shortage or can stock as much as possible if the space is available.

Therefore, consideration of spare parts inventory for systems with various spare parts applications that can divide as:

- M is a much necessary part, and L is a less necessity part.
- H is a high-cost part, and L is a low-cost part.
- F is a frequently used part, and S is a slowly used part.

Figure 2.2 shows the grouping of spare parts according to the above concept, which can be divided into eight groups according to various characteristics as mentioned above. Thus, each group will be directed to find an appropriate inventory model.

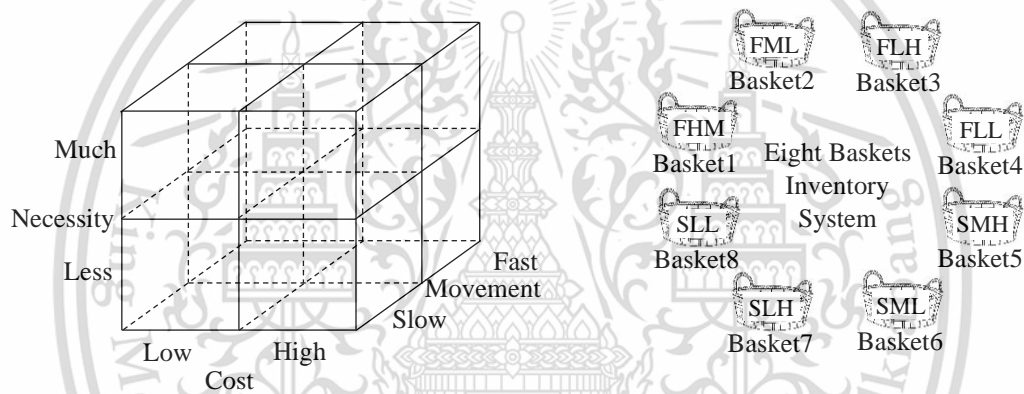


Figure 2.2 The basic concept of spare parts (MRO) classification and grouping according to necessity, price, and usage (or an eight-basket inventory system).

From the mentioned factors, it is possible to classify spare parts into eight distinct groups (baskets) conforming to the nature of spare parts characteristics:

Basket 1: Fast movement – Much necessity – High cost: (FMH)

Basket 2: Fast movement – Much necessity – Low cost: (FML)

Basket 3: Fast movement – Less necessity – High cost: (FLH)

Basket 4: Fast movement – Less necessity – Low cost: (FLL)

Basket 5: Slow movement – Much necessity – High cost: (SMH)

Basket 6: Slow movement – Much necessity – Low cost: (SML)

Basket 7: Slow movement – Less necessity – High cost: (SLH)

Basket 8: Slow movement – Less necessity – Low cost: (SLL)

Once grouped according to characteristics: price of spare parts, necessity of the machine, and speed of use. Then it will get eight groups of spare parts. Each group will be put into each basket. Or this type of spare parts division may be called an eight-basket inventory system. Each basket will be taken to find the appropriate spare parts inventory according to the EOQ Model principles.

1. How to measure the necessity factor (spare part is critical or non-critical)

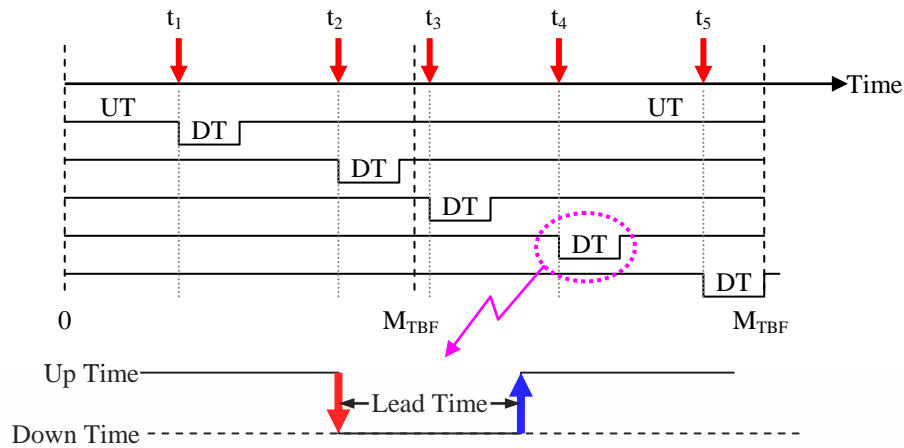
In terms of the necessity factor, the cost structure must be considered. For this study, costs can be separated into two types: production loss cost (or the cost of reducing production capacity) when a machine or system falls down, and spare parts inventory cost (or the cost of keeping spare parts in storage).

1.1 Production Loss Cost

Production loss cost may probably be called lost sale cost or lost opportunity in profitability because this is the cost occurring during maintenance downtime or when machines (or systems) fall into a down situation. And this cost is supposedly calculated based on no spare part(s) stocking in storage. Meaningfully, if a machine falls into failure status, then a new part will be purchased at all times, and there is no need to stock the part(s) as a spare. Production lost cost (P_{LC}) is the multiplication of production rate (P_R), percentage of affecting (from equipment breakdown) to overall production rate (p_{Aff}), maintenance downtime (M_{DT}), and profitable per unit (π), or the difference between product price sold (P_S) and input cost (P_C). So, production loss cost is:

$$\begin{aligned} P_{LC} &= P_R \cdot p_{Aff} \cdot M_{DT} \cdot (P_S - P_C) \\ &= P_R \cdot p_{Aff} \cdot M_{DT} \cdot \pi \end{aligned} \quad (38)$$

Assumption, all products can be sold without any scrap or defective products during the production period. There is no penalty cost from the shortage of the shortage of spare parts, which will be the cause of the reduction in production capacity. Thus, there is just a loss of opportunity cost in making profitability during the maintenance downtime.



t_i is represented as probability of equipment failure (start of downtime)

Figure 2.3 Chances of equipment failure compare against maintenance downtime.

Downtime (DT) represents the situation where the machine is in fail status, and Uptime (UP) represents the situation where the machine is in normal operation. The lead time (in this meaning) is the duration of waiting for spare parts since the machine breaks down (Order spare parts when you know the machine is broken) until the spare parts arrive in the area. Suppose the repair or spare part replacement time is minimal compared to the spare part waiting time.

For example, if a motor with gear (in the machine) breakdowns, the machine cannot operate, and the production rate of this machine is 100 pieces per hour; the percentage of affecting is 10% of the whole system; each breakdown will take around 2 hours for recovery; and the product price sold is 200 Baht with an input cost of 80 Baht per unit. Therefore, the production loss cost is:

$$P_{LC} = 100 * 0.10 * 2 * (200 - 80) = 1,200 \text{ Baht}$$

Meaningfully, this factory will lose the opportunity to make a profit equal to 1,200 Baht during maintenance downtime (2 hours).

For this study, the term maintenance downtime is always represented by part (or device) delivery lead time, because spare part delivery lead time (L) is quite much longer than maintenance downtime, and this is thought to be based on no spare part stocked. So, equation (27) can be rewritten as:

$$P_{LC} = P_R \cdot p_{Aff} \cdot L \cdot \pi \quad (39)$$

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In general, production loss cost of this study in equation (39) is calculated by based on thinking about only commercial issue. But there are more relevant issues, such as safety issues and environmental issues that relate to production losses. Therefore, equation (39) can be rewritten in terms of the relevant issues as:

$$PL_C = C_I + S_I + E_I \quad (40)$$

Where: C_I is lost cost from commercial issue.

S_I is lost cost from safety issue.

E_I is lost cost from environmental issue.

Basically, safety issues and environmental issues can be converted to commercial issues based on the compensation of the lost value (equivalently, the loosening of money) during the incident of occurrence if a safety issue or environmental issue occurs. However, this study considers only commercial issues because safety issues and environmental issues are difficult to convert to loosening value (or loosening of money), and this is not the main purpose of this study.

1.2 Total Inventory Cost

Inventory cost always includes all relevant costs, such as part depreciation cost and interest rate cost, which come from the need to have spare parts. Inventory costs are a combination of purchasing cost and holding costs. Whereas total holding cost (TH_C) is the multiplication of material cost (C) and the summation of interest rate cost, equipment depreciation cost, and the other relevant costs, which are expressed in percentage (I) of holding cost (or fraction factor), which is thought to be the annual period. So, the total holding cost can be shown as:

$$TH_C = C \cdot I \quad (41)$$

According to figure 2.4, machine failure may occur during (at t_i equal to) zero until infinity. However, there is an exact time of the average for machine breakdown, which is equal to the period of equipment needed occurrences. This is defined as the mean time between failures (M_{TBF}). Or, spare part(s) are totally consumed in one set (or m units) in every mean time between failures by average.

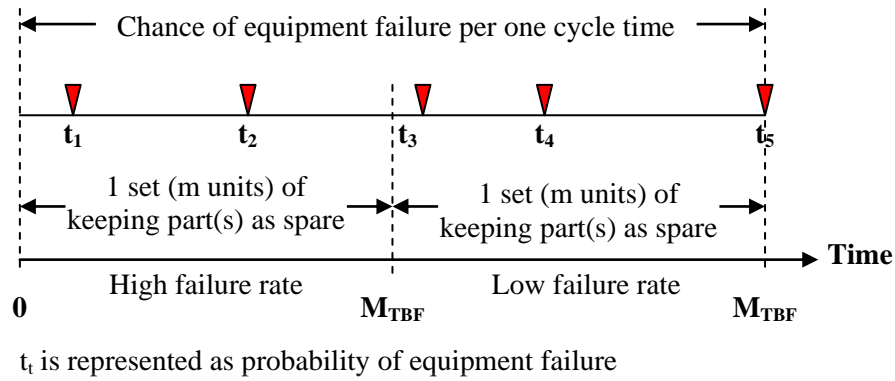


Figure 2.4 Equipment failure occurrences

Basically, if the purchasing cost is waived by the reason that a part is either to be bought now (for keeping it as a spare and using it for replacement in the future) or postponed to be bought in the future (no part to be spared now but to be bought when failure occurs), then it is not necessary to think about the purchasing cost. However, spare parts are probably stocked within the mean time between failures (M_{TBF}) before they are used to replace the existing defective part (if the factory decides to have a spare). Then, spare parts must be stocked during equipment's mean time between failures (M_{TBF}), and equation (41) can be rewritten as:

$$TH_C = C \cdot I \cdot M_{TBF} \quad (42)$$

If there are m pieces of device (or parts) that are simultaneously changed, such as 4 battery cells, double-driving V-belts of the gear motor, or 10 meters of belt length, etc. Thus, equation (42) should add the term m to this equation as:

$$TH_C = m \cdot C \cdot I \cdot M_{TBF} \quad (42)$$

Assumption, all components (or parts) are supposedly identical, independent, and uncorrelated with each other, and these components have the same characteristics and similar behavior of failure.

If there are k identical components installed in the system. For example, three circuit breakers are installed in the system, and ten light bulbs are installed in the system. Thus, equation (42) can be rewritten as:

$$TH_C = m \cdot C \cdot I \cdot \left(\frac{M_{TBF}}{k} \right) \quad (43)$$

$$\text{Or: } TH_C = m \cdot C \cdot I \cdot \theta \quad (44)$$

Where: θ is system mean time between failures.

1.3 Comparison between productions lost cost and inventory cost

The production loss cost is compared against the inventory cost. Figure 4 can be exploited as a representation of the criticality concept. Whereas, the ratio production lost cost to holding cost (R_{PH}) can be shown as:

$$R_{PH} = \frac{PLC}{TH_C} \quad (45)$$

According to figure 5, if the production loss cost is greater than the total holding cost (or $R_{PH} > 1$), then that component or part seems to be a critical part or a necessity for the system. Contrary to this, if the production loss cost is lower than the total holding cost (or $R_{PH} < 1$), then that part or piece of equipment seems to be non-critical or is not a necessity for the system.

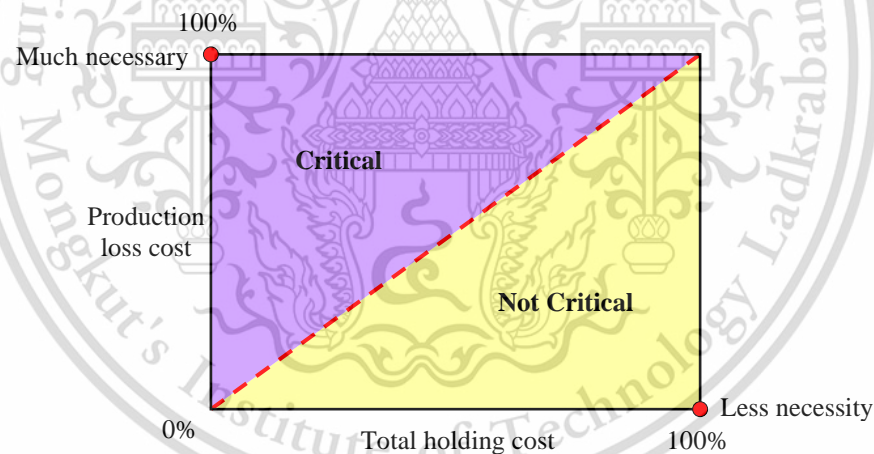


Figure 2.5 Measurement of the criticality

Meaningfully, if a component (or part) is installed at an unimportant location in the system, whenever that part or piece of equipment breakdowns, we can wait for a new part to replace the existing defective part until the production loss cost is equal to the total holding cost. If there is a tendency to produce much more production loss during downtime (after machine breakdowns), which includes equipment delivery lead time, diagnosis time, and other waste time, then that component (or part) seems to be very essential. Contrary to this, it seems to be nonessential.

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Example: The machine has production rate is 100 pieces per day, the product sell price is 50 Baht, the input cost is 30 Baht per unit, and the machine has a 10% overall affection. There are two comparison cases of delivery lead time; the first case is 15 days, and the second is 90 days.

So, the production loss cost in the first case is:

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

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

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

While each motor with gear cost is 50,000 Baht, the holding cost is 10% of the equipment value per year, and the mean time between failures is 30 months (2.5 years). So, the total holding cost is:

$$TH_C = 1 \cdot 50,000 \cdot 0.10 \cdot 2.5 = 12,500 \text{ Baht}$$

Regarding the above example, 3,000 and 18,000 Baht are the lost costs of reducing production capacity (or profitability) during maintenance downtime without any spares in storage. And 12,500 Baht is the inventory cost or cost of having a spare part (a motor with gear must be stocked during its M_{TBF}). Conclusively, the spare part in the second case can be inferred as a critical part, while the first case can be inferred as a non-critical part.

1.4 Concept supporting the safety stock

Regarding the critical part, safety stock is very important for ensuring that part can be in hand at all. Therefore, safety stock must be concerned in order to cover the chances of spare parts stocking out. By the comparison between production loss cost and spare parts holding cost, safety stock is equal to production loss cost divided by spare part holding cost (during its M_{TBF}). So, safety stock (SS) is:

$$SS = \frac{P_R \cdot P_{aff} \cdot \pi \cdot L}{CI \cdot M_{TBF}} \quad (46)$$

If there are k identical components installed in the system, then equation (46) can be rewritten as:

$$SS = \frac{P_R \cdot P_{aff} \cdot \pi \cdot L}{C \cdot I \cdot \theta} \quad (47)$$

The safety stock of equation (47) is the maximum number. If it is greater than this number, then spare parts holding costs will be greater than production loss costs, so there is no benefit to having spare parts stock as a safety stock. In addition, if production loss is a big value, then a lot of spares will also be stocked. Thus, safety stock should be compared against some criteria, such as the maximum failure rate on lead time or the amount of equipment installed in the machine. However, demand on lead time (or machine failure on lead time) is the most reasonable. In terms of constant lead time, failures during lead time are a continuous pattern. So, safety stock can be rewritten as:

$$SS = \text{Min} \left[\varphi, \frac{P_R \cdot p_{aff} \cdot \pi \cdot L}{C \cdot I \cdot \theta} \right] \quad (48)$$

Where: φ is the multiplication number of demands during lead time; see the explanations of safety stock concept in previous chapter.

For non-critical parts, spare parts can be allowed to be in shortage, and re-order points can be delayed until the maximum time for allowing spare parts to be in shortage ($T_W + L$), which is the time that production loss cost equals holding cost (if it is equivalency of necessity to have parts as spare). And, allowing time ($T_W + L$) is equal to:

$$(T_W + L) = \frac{C \cdot I \cdot m \cdot \theta}{P_R \cdot p_{aff} \cdot \pi} \quad (49)$$

Or:
$$T_W = \left(\frac{C \cdot I \cdot m \cdot \theta}{P_R \cdot p_{aff} \cdot \pi} \right) - L \quad (50)$$

Whereas, T_W represents the allowing time of a shortage of a shortage of spare parts before purchasing a new order or time before re-ordering. This allowing time ($T_W + L$) is very important because we can exploit it to reduce the holding cost of the EOQ model by delaying the re-order point until it equals this time. And the holding cost can be equally reduced to $C \cdot I \cdot m \cdot \left[\frac{T_W + T}{T} \right]$, where T is purchasing period.

2. How to measure the movement factor (Frequency of usage)

In terms of the movement factor, finding the separation line between slow and fast movement is the aim of this issue. In this sense, the boundary between continuous and discrete pattern will be important for sustaining and classifying the spare parts, which are either slow or fast movements. The slow movement is inferred as a discrete pattern. Otherwise, fast movement is inferred as a continuous pattern. Actually, spare parts are always consumed according to a

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discrete pattern. But this study has assumed that fast-moving items can be supposedly formed as a continuous pattern (which can be applied to an EOQ model).

Generally, slow-moving items (or discrete demand) can be implied as a non-continuous pattern, or components are scarcely used. Indeed, the exact separation between a discrete and continuous pattern (of demand) is not surely defined. Nevertheless, there are too many text books, articles, and case studies that were given the definitions of discrete demand in many different types or several formats, such as parts that are consumed less than one unit within an annual period (Siasiriwattana et al., 2006; Pintelon et al., 1997), items that are withdrawn less than one item in a quarter (Gopalakrishnan, 2005), parts that have been issued or sold at least once within the last year (Gopalakrishnan and Banerji, 2006), demand per year equal to or less than three (Kelly, 2006), the stock of such items that take two years or more to exhaust (Dutta, 2004), and items where the mean time between demands is much longer than ten times the average lead time (Hastings, 2009). And Tersine (1994) explained that the Poisson distribution is not commonly applicable to distributions with mean values above 20, thus only slow-moving items are commonly described by this distribution.

Practically, the imaginary line (or boundary) separating continuous and discrete patterns is a consideration for the exploitation of Poisson statistics (which is converted from binomial statistics) and Poisson estimation using normal distribution statistics, as discussed in previous chapters. The approximation is good for $\lambda > 5$ during an observed period (refer to Montgomery and Runger, 2011).

However, the point of view for this study is to go along with the definition of Montgomery and Runger (2011). Thus, a fast-moving item is an item whose mean use or average annual demand is more than 5 units. As per this guideline, if the failure rate is more than 5 units, then this item can be implied as a fast movement. Contrary, it can be implied as a slow-moving item.

If there are k identical components (or parts) installed in the system, the equation can be shown as:

$$\lambda_s \leq 5 \text{ units or } \theta \geq 0.2 \text{ year} \quad (51)$$

This sense always corresponds to the movement factor of this study. It can be suitably applied to form the models of this research study. And, the suggestion of item stocking as above will be adapted in accordance with this study.

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3. How to measure the cost factor (spare part is high or low cost)

In terms of the cost factor, the consideration of parts purchasing is concerned with thinking about the minimum total inventory cost. So, the comparison between the lot-for-lot (LFL) model and the economic order quantity (EOQ) model will be considered in order to minimize total inventory costs.

3.1 Cost factor of fast-moving item

Fast-moving items can be implied as continuous demand, and this can be suitably applied to the EOQ model. Nevertheless, the EOQ model may sometimes not be the cheapest to buy. Spare part holding costs will be the reason for this problem. Particularly, high-cost materials will produce more holding costs than low-cost materials. Then, some alternative way may probably be, accordingly, the lowest total inventory cost.

3.2 Lot-For-Lot (LFL) model

Lot-For-Lot ordering is the simplest approach of all. An order is scheduled for each period in which a demand occurs. Items are purchased in the exact quantities (or number of equipment breakdowns) for each period. So, no items are held over from period to period. Hence, this approach virtually eliminates the inventory holding cost because there is a zero-inventory balance at the end of each period (Tersine, 1994). Therefore, the LFL model has only ordering costs without spare parts holding cost. And the total ordering cost is equal to the number of purchasing times within the observed period multiplied by the cost of ordering per time. The fast-moving item is observed by the annual period. Then, the total inventory cost (TC_{LFL}) of the LFL model is:

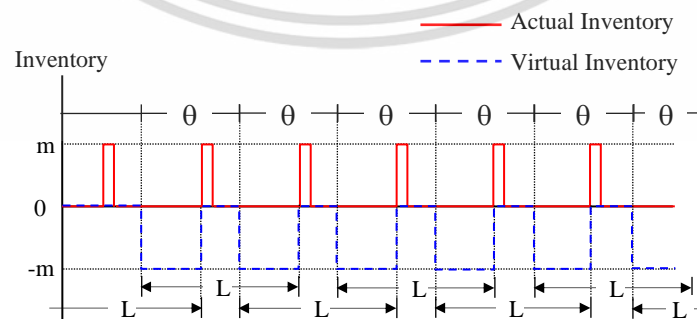


Figure 2.6 Principle of Lot-for-Lot model concept (Fast moving items)

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Total inventory cost = Ordering cost

$$TC_{LFL} = S \cdot k \cdot \lambda \quad (52)$$

Where: S is ordering cost

λ is equipment failure rate

k is identical components (parts) installed in the system.

Notice: equation (52) as above is not dependent on m units, which are contemporaneously changed at the same time. Because spare parts (m units) are changed within one time, it does not affect the equation.

3.3 Economic Order Quantity (EOQ) model

The order size is considered by minimizing the total inventory cost, which is well known as the economic order quantity (EOQ). Total inventory cost (TC_{EOQ}) is a combination of ordering (set-up) cost and holding cost, as follows:

Total inventory cost = Ordering cost + Holding cost

$$\begin{aligned} TC_{EOQ} &= \left(\frac{S \cdot D}{Q}\right) + H_C \cdot \left(\frac{Q}{2}\right) \\ &= S \cdot \left(\frac{mk\lambda}{Q^*}\right) + CI \cdot \left(\frac{Q^*}{2}\right) \end{aligned} \quad (53)$$

Where: S is ordering cost

m is components (parts) which are simultaneous changed.

k is identical components installed in the system.

C is material (or part) unit cost.

I is holding cost fraction (in percentage of material cost).

λ is equipment failure rate.

Q^* is economic order quantity.

3.4 Comparison between Lot-For-Lot (LFL) model and Economic Order Quantity (EOQ) model

The comparison between the LFL and EOQ models is considered according to the minimum total inventory cost and which one is the cheapest. Thus, the comparison between the two approaches can be shown by the following equations:

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$$TC_{LFL} = TC_{EOQ}$$

$$Sk\lambda = S \cdot \left[\frac{mk\lambda}{Q^*} \right] + CI \cdot \left[\frac{Q^*}{2} \right]$$

$$\text{Where: } Q^* = \sqrt{\frac{2S(mk\lambda)}{CI}} = \sqrt{\frac{2Sm}{CI\theta}}$$

$$\text{Then: } C^* = \frac{Sk\lambda}{2mI}$$

$$\text{Or: } C^* = \frac{S}{2mI\theta} \quad (54)$$

Regarding equation (54), if spare part unit cost (C) is greater than this ratio, then it can be implied as high-cost material, and it should be purchased using the LFL model. Contrary to this, if spare part unit cost (C) is lower than this ratio, then it can be implied as low-cost material, and it should be purchased using the EOQ model.

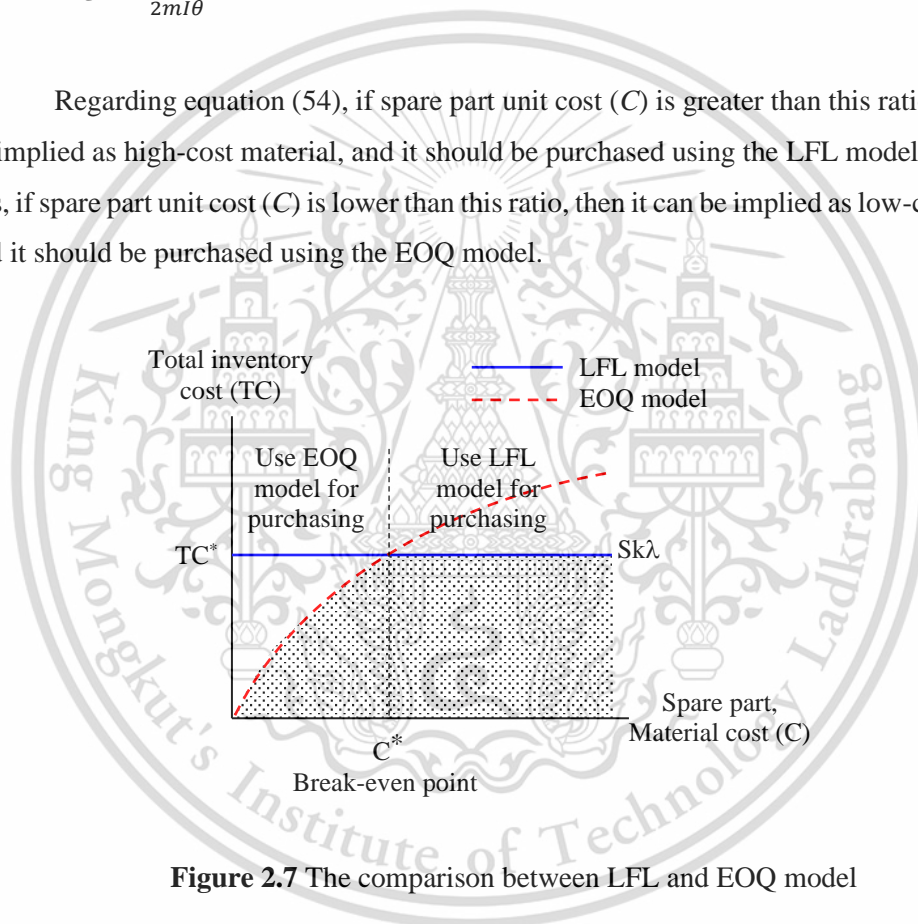


Figure 2.7 The comparison between LFL and EOQ model

Note: proof of equation (54), and Figure 2.7 are shown in appendix A.

According to Figure 2.7, this figure represents the possibility area of the combination between the LFL and EOQ models. The area of interest is the dotted area. Otherwise, it is out of consideration (or a non-possible area). Whereas C^* is the break-even point between high- and low-cost spare parts.

3.5 Cost factor of slow-moving item

Indeed, the EOQ model is developed for continuous and independent demand items. This model assumes that demand occurs with certainty at a constant rate, while discrete demand occurs at discrete intervals or points in time rather than continuously over a time horizon. Demand requirements are usually time-phased in equal time increments over a finite time horizon. Uneven or lumpy demand requirements occurring over a finite time horizon complicate the lot sizing decision, such as the utilization of spare parts consumption or spare parts demand (Tersine, 1994).

Supposedly, there are 4 sets of circuit breakers installed in a system, and the MTBF of each breaker is 20 years. So, failure rate is 0.05 and annual demand is 0.2 sets, while the unit price of a circuit breaker is 30,000 Baht, the ordering cost is 10,000 Baht, and the holding cost is 4%. Thus, the purchasing quantity is equal to 2 sets (if it is calculated by the general EOQ model). For this case, every ten years, we will purchase two sets of breakers (or one set of circuit breaker has been used every five years).

Referring to equation (53), if it is calculated using the general EOQ model, then the total inventory cost is:

$$\begin{aligned} TC_{EOQ} &= S \left(\frac{mk\lambda}{Q^*} \right) + CI \left(\frac{Q^*}{2} \right) \\ &= 1,000 + 1,200 = 2,200 \text{ Baht per year} \end{aligned}$$

Or: $TC_{EOQ} = 44,000$ Baht per 20 years (or M_{TBF})

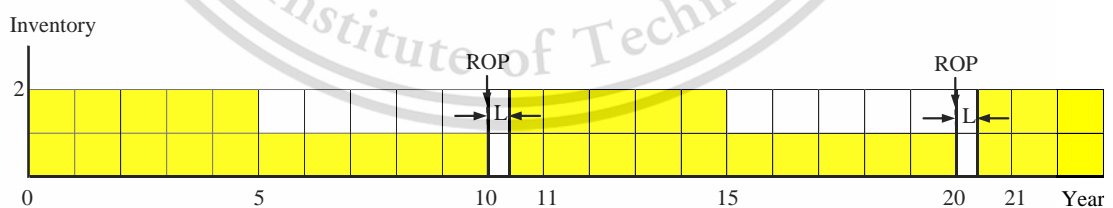


Figure 2.8 The holding cost calculation for general EOQ model

According to Figure 2.8, each yellow block is represented by parts stocking (or holding cost), which is equal to material (or spare part) unit cost (C) multiplied by the holding cost fraction (I). Thus, each block is equal to $30,000 * 0.04 = 1,200$ Baht. There is a total of 30 blocks, so the total holding cost is 36,000 Baht per 20 years (M_{TBF}). During 20 years, circuit

breakers are equally purchased twice (in year 0 and at the end of year 10). Then, the ordering cost is equal to $2 \cdot 10,000 = 20,000$ Baht (for 20 years). Thus, the total inventory cost is 56,000 Baht. This value is not the same as the previous.

If n is defined as the optimal purchasing quantity. So, the extension EOQ model can be shown as the following:

$TC_{EOQ} = \text{Ordering Cost} + \text{Holding Cost}$

$$\begin{aligned}
 TC_{EOQ} &= S \cdot \left(\frac{k}{n}\right) + CI \cdot m \cdot \left(\sum_{i=1}^n i\right) \cdot \left(\frac{M_{TBF}}{n}\right) \\
 &= S \frac{k}{n} + CI \cdot m \left[\left(\frac{n}{2}\right) \cdot (n+1)\right] \cdot \left(\frac{M_{TBF}}{n}\right) \\
 &= S \frac{k}{n} + CI \cdot m \cdot \left(\frac{n+1}{2}\right) \cdot M_{TBF}
 \end{aligned} \tag{55}$$

DWT TC to n : $\frac{dTC}{dn}$ and set it as zero, then:

$$\frac{dTC}{dn} = -\frac{Sk}{n^2} + CI \cdot m \left(\frac{M_{TBF}}{2}\right) = 0$$

$$\text{Thus: } n = \sqrt{\frac{2Sk}{CI \cdot m \cdot M_{TBF}}} = \sqrt{\frac{2S}{CI \cdot m \cdot \theta}} \tag{56}$$

And: $p = j \cdot m$

Where: p is actual purchasing quantity.

j = rounding number of n (lot size of m units)

Or: j is actual purchasing lot-size (of m units).

According to equation (55), the ordering cost is 20,000 Baht, the holding cost is 36,000 Baht, and the total inventory cost (to have a circuit breaker as a spare part) is 56,000 Baht.

3.6 The modification of the extension of EOQ model

Practically, the exact time of equipment failure cannot be surely known. Then, the new parts will be replaced when the existing one's breakdown. And the average purchasing time is still equal to the mean time between failures.

Referring to equation (55), if the model is considered based on Figure 2.9, then this equation can be rewritten as:

$$\begin{aligned} TC_{EOQ} &= S \left(\frac{k}{n} \right) + C I m \cdot \left(\frac{n}{2} \right) (n - 1) \left(\frac{M_{TBF}}{n} \right) \\ &= S \left(\frac{k}{n} \right) + C I m \left(\frac{n-1}{2} \right) M_{TBF} \end{aligned} \quad (58)$$

DWT TC_{EOQ} to n and set it as zero

$$\text{Then: } \frac{dTC_{EOQ}}{dn} = -S \frac{k}{n^2} + \frac{CI}{2} m \cdot M_{TBF} = 0$$

$$n = \sqrt{\frac{2Sk}{CI m M_{TBF}}} = \sqrt{\frac{2S}{CI m \theta}} \quad (59)$$

The optimal purchasing lot size (n) of equation (59) as above is same as equation (56).

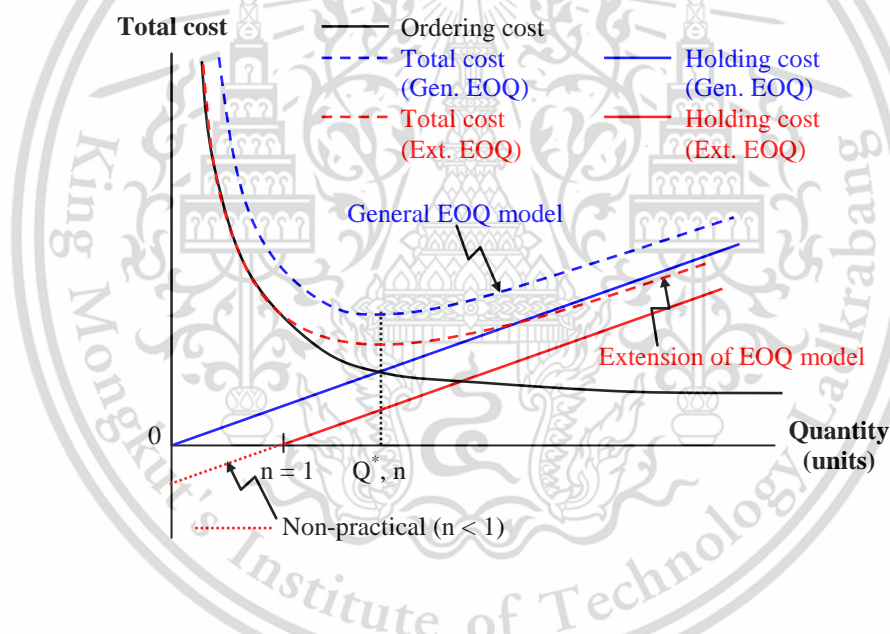


Figure 2.10 Comparison (for total inventory cost) between general EOQ model and extension of EOQ model.

Regarding Figure 2.10, this is the plot of total inventory cost by comparing the general EOQ model and the extension EOQ model. The figure shows that the extension EOQ model has lower costs than the general EOQ model at all.

Note: - Proofs of equations (56) and (59) are shown in Appendix B. And the explanations with a case study of example equipment are shown in Chapter 4.

The extension EOQ model cannot be applied to some parts where the measurement unit is a continuous pattern, such as conveyor belts, chains, electrical cables, oil and lubricant, etc. It has to apply to the measurement unit as a piece.

Referring to equation (46), this equation will be true when spare part lead time is very short (or assumed to be zero) if compared with the system mean time between failures, (Or $L \ll \theta_j$). And, purchasing lots (or n) must be more than one ($n > 1$). As a result, the lot size purchased remains the same as before, but the total cost differs. Particularly, the term of holding cost is always reduced because parts can be allowed to be in shortage (for non-critical parts) or safety stock is firstly used (for critical parts).

3.7 Principle of LFL model for discrete demand

In the case of slow-moving items, equipment delivery lead time (L) is shorter than the system mean time between failures (θ). But for fast-moving items, the lead time is longer than the system mean time between failures. As in the case of fast-moving items, total inventory cost has only ordering cost without any holding cost. Then, the total inventory cost (TC_{LFL}) of the LFL model (during M_{TBF}) is:

$$TC_{LFL} = \text{Ordering cost} = S \cdot k$$

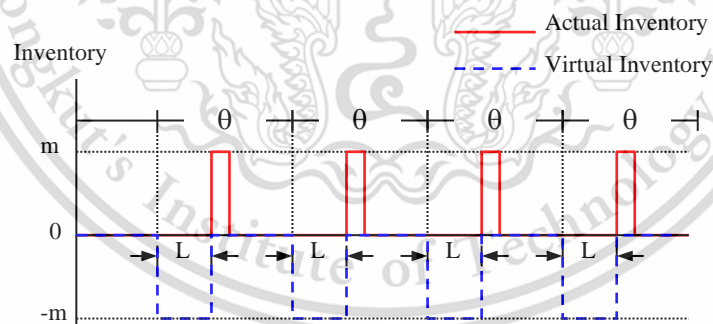


Figure 2.11 Principle of Lot-for-Lot model concept (Slow moving item)

Notice: that the total inventory cost of the LFL model (for slow moving analysis) is based on equipment life time (or M_{TBF}), whereas the total inventory cost has only ordering cost multiplied by identical components, which is not the same as in fast moving analysis. Because fast movement analysis is observed based on the annual period, but slow movement analysis is observed based on equipment life.

3.8 Comparison between LFL model and Extension EOQ model

The comparison between the total inventory cost of the Extension EOQ model and the LFL model is issued in order to minimize the total inventory cost as follows:

At the break-even point:

$$TC_{LFL} = TC_{EOQ}$$

$$Sk = \frac{Sk}{n} + C Im \cdot \left(\frac{n-1}{2}\right) M_{TBF}$$

$$\text{Then: } C^* = \frac{2Sk}{Im M_{TBF}} = \frac{2S}{Im \theta} \quad (60)$$

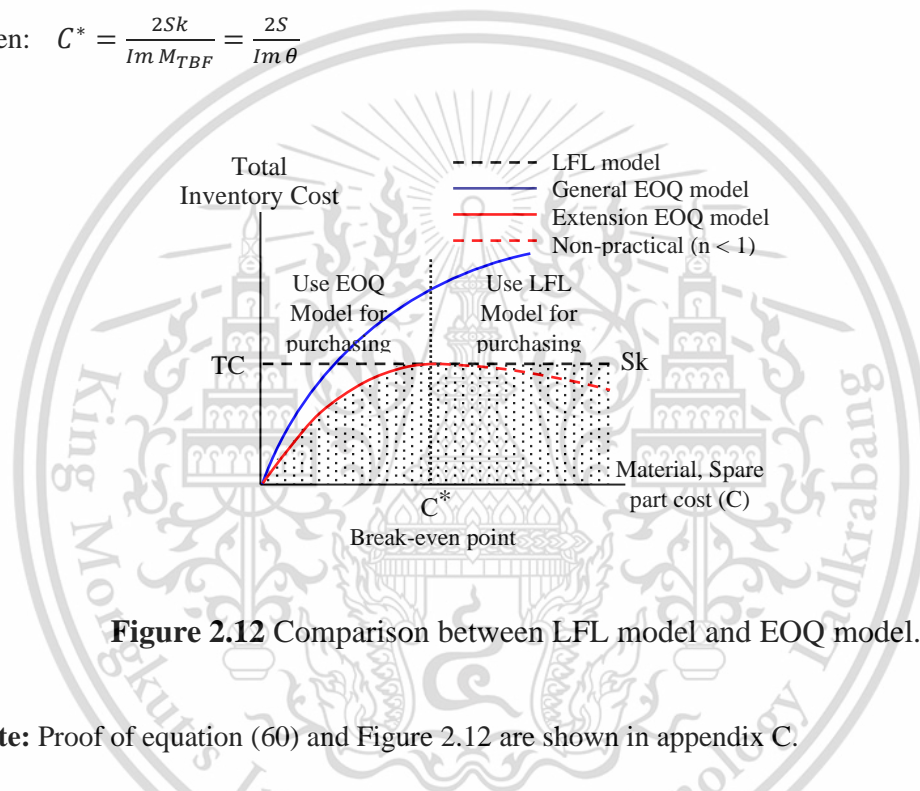


Figure 2.12 Comparison between LFL model and EOQ model.

Note: Proof of equation (60) and Figure 2.12 are shown in appendix C.

Regarding equation (48), this is the separation line of the boundary between high- and low-cost materials. If spare part unit cost (C) is greater than this ratio (C^*), then it can be implied as high-cost material, and it should be purchased using the LFL model. Contrary to this, if spare part unit cost (C) is lower than this ratio (C^*), then it can be implied as low-cost material, and it should be purchased by using the Extension EOQ model.

2.6 Eight baskets inventory system

The eight-basket inventory system is based on the classification of spare parts (MRO) consumption's characteristics. This concept applies the classification between high and low criteria for the three main factors: movement, necessity, and cost. Regarding Table 4, this table is used to illustrate the criteria for the separation between high and low conditions of the three main contribution factors, as mentioned before.

Table 2.6 Summary of the criteria for the spare parts (MRO) classification conforms to the three main factors.

Factor	Criteria	Expression	Contribution/ Application
Movement	Frequency of parts using	Fast ($\theta \leq 0.2$)	Assume to be Continuous pattern
		Slow ($\theta > 0.2$)	Assume to be Discrete pattern
Necessity	Ratio of Opportunity cost (or Production loss cost) per Inventory cost: PL_C/TH_C	Much (Ratio ≥ 1)	Critical part (material) / MRO cannot be stock out (No Shortage, or having Safety stock)
		Less (Ratio < 1)	Non-critical part (material)/ MRO can be shortage (Available to be shortage, or having Safety stock)
Cost	Ratio: $S/2ml\theta$ (Fast movement) or: $2S/ml\theta$ (Slow movement)	High (Ratio ≥ 1)	High cost material, Purchase by using LFL model
		Low (Ratio < 1)	Low cost material/ Purchase by using EOQ model

According to the criteria in Table 2.6, classification according to conditions is shown in the table. So, spare parts (MRO) can be separated into 8 baskets (or groups) by applying these three main factors:

According to the previous paragraphs, the eight baskets and their individual inventory model are shown according to the demand for spare parts (MRO). The conclusion of the eight basket inventory models is shown in Table 8 as follows:

Table 2.7 Conclusion of Eight Baskets Inventory System

Factor			Demand Type	Characteristics of Model			Basket No.	Number Represent
Movement	Necessity	Cost		Distribution Pattern	Safety stock	Purchasing by using		
Fast	Much	High	FMH	Contrinuous	Yes	LFL	Basket 1	1-1-1
		Low	FML	Contrinuous	Yes	EOQ	Basket 2	1-1-0
	Less	High	FLH	Contrinuous	No	LFL	Basket 3	1-0-1
		Low	FLL	Contrinuous	No	EOQ	Basket 4	1-0-0
Slow	Much	High	SMH	Discrete	Yes	LFL	Basket 5	0-1-1
		Low	SML	Discrete	Yes	EOQ	Basket 6	0-1-0
	Less	High	SLH	Discrete	No	LFL	Basket 7	0-0-1
		Low	SLL	Discrete	No	EOQ	Basket 8	0-0-0

Note: The numbers of fast, high, and much are represented by one, while slow, less, and low are represented by zero.

Basket 1 – (Fast-Much-High: FMH)

This basket contains MRO (spare parts) with fast movement, much necessity, and high-cost spare parts. So, this basket can be managed by applying the LFL model with safety stock, and this can be implied as a continuous pattern.

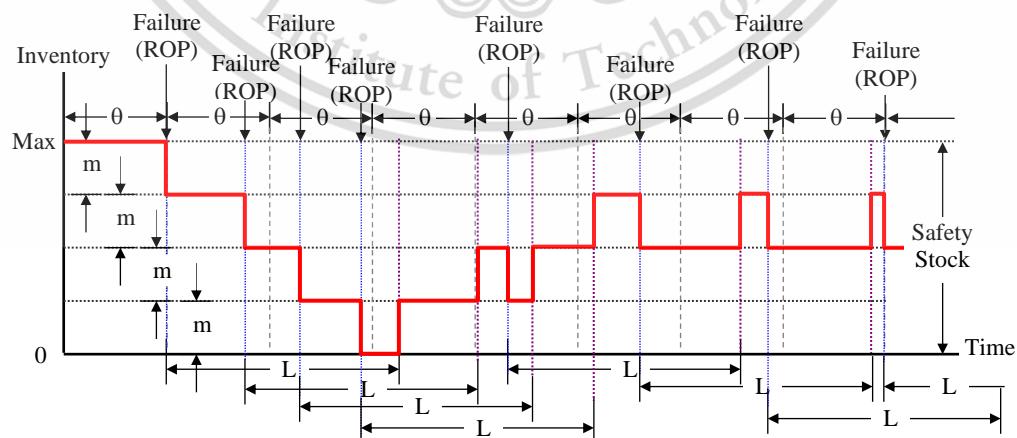


Figure 2.13 Inventory model of Basket 1 or spare parts (MRO) demand is fast movement, much necessity, and high cost spare parts.

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Re-Order Point (ROP) = machines failure (breakdown)

Purchasing Quantity (Q^*) = m units (or amount of each machine breakdowns)

$$\text{Safety stock (SS)} = \text{Min}\left[\phi, \frac{P_R \cdot p_{aff} \cdot \pi \cdot L}{CI \cdot \theta}\right]$$

When machines breakdown, safety stock (m units) will be used in order to replace the existing defective parts. And the new replenishment parts (m units) will be purchased as soon as possible (within one day).

Basket 2 – (Fast-Much-Low: FML)

This basket contains MRO (spare parts) with fast movement, much necessity, and low-cost spare parts. So, this basket can be managed by applying the EOQ model with safety stock, and this can be implied as a continuous pattern.

Re-Order Point (ROP) = spare parts lead time

$$\text{Purchasing Quantity (} Q^* \text{)} = \sqrt{\frac{2S(mk\lambda)}{CI}} = \sqrt{\frac{2Sm}{CI\theta}}$$

$$\text{Safety stock (SS)} = \text{Min}\left[\phi, \frac{P_R \cdot p_{aff} \cdot \pi \cdot L}{CI \cdot \theta}\right]$$

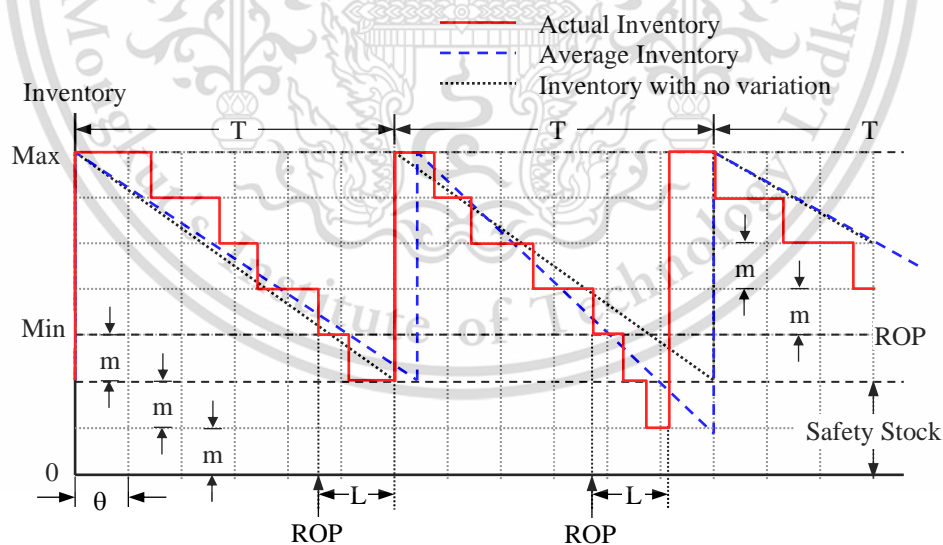


Figure 2.14 Inventory model of Basket 2 or spare parts (MRO) demand is fast movement, much necessity, and low-cost spare parts.

The purchasing quantity will be conformed to the EOQ model (or purchasing every T period). And the new replenishment parts will be purchased at the parts lead time.

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Basket 3 – (Fast-Less-High: FLH)

This basket contains MRO (spare parts) with fast movement, less necessity, and high-cost spare parts. So, this basket can be managed by applying the LFL model without any safety stock (spare parts can be a shortage), and this can be implied as a continuous pattern.

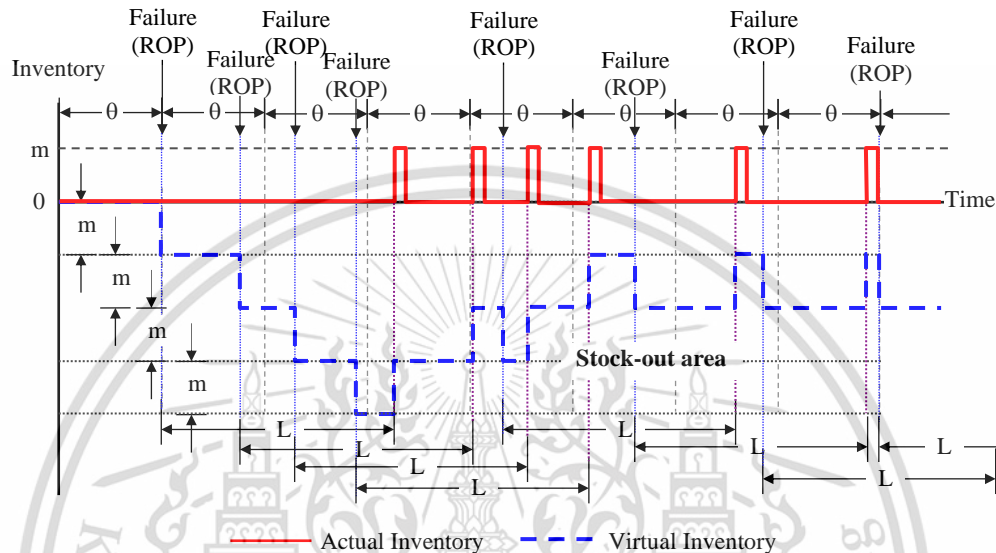


Figure 2.15 Inventory model of Basket 3 or spare parts (MRO) demand is fast movement, less necessity, and high cost spare parts.

Re-Order Point (ROP) = machines failure (breakdown)

Purchasing Quantity (Q^*) = m units (or amount of each machine breakdowns)

Safety stock (SS) = no safety stock (or spare parts can be shortage)

When machines breakdown, spare parts can be a shortage, and we can wait until new parts (m units) arrive on site after ordering (or until parts lead time). But the new parts (m units) have to be purchased as soon as possible (within one day) whenever machines breakdown.

Basket 4 – (Fast-Less-Low: FLL)

This basket contains MRO (spare parts) with fast movement, less necessity, and low-cost materials. So, this basket can be managed by applying the EOQ model without any safety stock, and this can be implied as a continuous pattern.

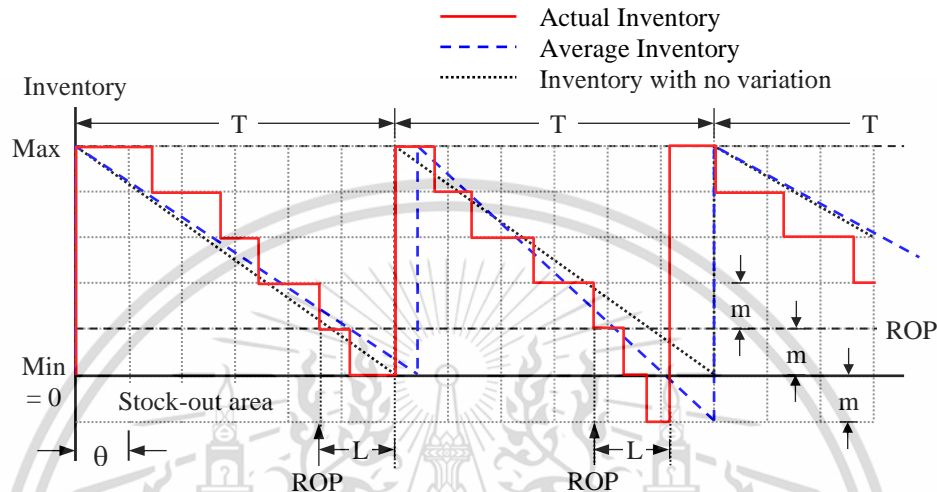


Figure 2.16 Inventory model of Basket 4 or spare parts (MRO) demand is fast movement, much necessity, and low-cost spare parts.

Re-Order Point (ROP) = parts lead time

$$\text{Purchasing Quantity } (Q^*) = \sqrt{\frac{2S(mk\lambda)}{CI}} = \sqrt{\frac{2Sm}{CI\theta}}$$

Safety stock (SS) = no safety stock (or spare parts can be shortage)

The purchasing quantity will be conformed to the EOQ model (or purchasing every T period). And the new replenishment parts will be purchased at parts lead time, but spare parts can be a shortage.

Basket 5 – (Slow-Much-High: SMH)

This basket contains MRO (spare parts) with slow movement, much necessity, and high cost spare parts. So, this basket can be managed by applying the LFL model with safety stock and this is can be implied as the discrete pattern.

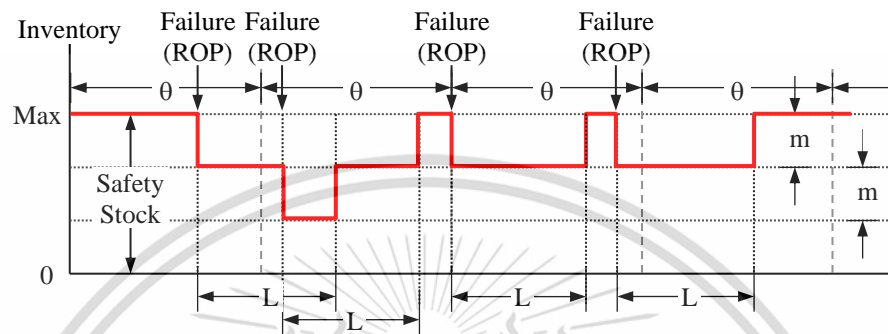


Figure 2.17 Inventory model of Basket 5 or spare parts (MRO) demand is slow movement, much necessity, and high-cost spare parts.

Re-Order Point (ROP) = machine failure (breakdown)

Purchasing Quantity (Q^*) = m units (or amount of each machine breakdowns)

$$\text{Safety stock (SS)} = \text{Min} \left[\phi, \frac{P_R \cdot v_{aff} \cdot \pi \cdot L}{CI \cdot \theta} \right]$$

When machines breakdown, safety stock (m units) will be used in order to replace the existing defective parts. And the new replenishment parts (m units) will be purchased as soon as possible (within one day).

Basket 6 – (Slow-Much-Low: SML)

This basket contains MRO (spare parts) with slow movement, much necessity, and low-cost spare parts. So, this basket can be managed by applying the EOQ model with safety stock, and this can be implied as a discrete pattern.

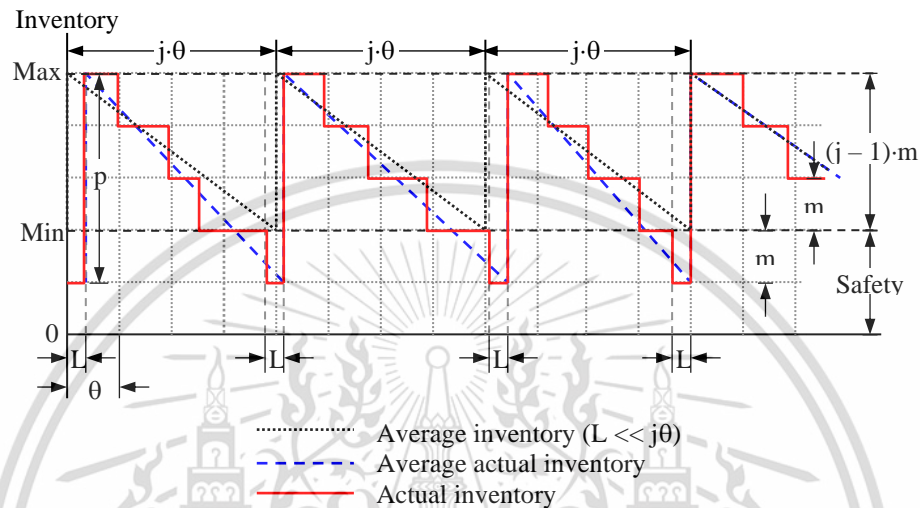


Figure 2.18 Inventory model of Basket 6 or spare parts (MRO) demand is slow movement, much necessity, and low-cost spare parts.

Re-Order Point (ROP) = parts lead time

Purchasing Quantity (p) = $j \cdot m$

And: j = rounding number of n (lot size of m units)

$$\text{By: } n = \sqrt{\frac{2Sk}{CImM_{TBF}}} = \sqrt{\frac{2S}{CIm\theta}}$$

$$\text{Safety stock (SS)} = \text{Min} \left[\varphi, \frac{P_R \cdot p_{aff} \cdot \pi \cdot L}{CI \cdot \theta} \right]$$

The purchasing quantity will be conformed to the EOQ model (or purchasing every $j \cdot \theta$ period). And the new replenishment parts will be purchased at parts lead time.

Basket 7 – (Slow-Less-High: SLH)

This basket contains MRO (spare parts) with slow movement, less necessity, and high-cost spare parts. So, this basket can be managed by applying the LFL model by without any safety stock (spare parts can be shortage) and this is can be implied as the discrete pattern.

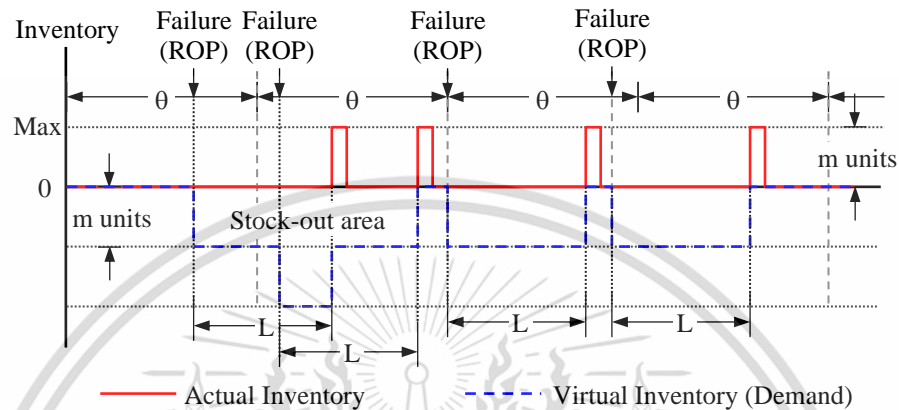


Figure 2.19 Inventory model of Basket 7 or spare parts (MRO) demand is slow movement, less necessity, and high-cost spare parts.

Re-Order Point (ROP) = machines failure (breakdown)

Purchasing Quantity (Q^*) = m units (or amount of each machine breakdowns)

Safety stock (SS) = no safety stock (or spare parts can be shortage)

When machines breakdown, spare parts are allowed being shortage, and we can wait until new parts (m units) arrive on site after ordering (or until part lead time). But the new parts (m units) have to be purchased as soon as possible (within one day) whenever machines breakdown.

Basket 8 – (Slow-Less-Low: SLL)

This basket contains MRO (spare parts) with fast movement, less necessity, and low-cost materials. So, this basket can be managed by applying the EOQ model without any safety stock, and this can be implied as a discrete pattern.

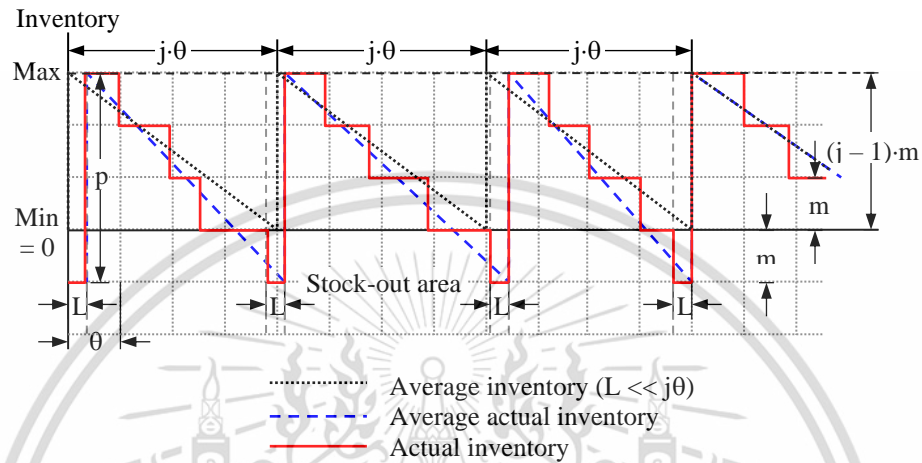


Figure 2.20 Inventory model of Basket 8 or spare parts (MRO) demand is slow movement, less necessity, and low-cost spare parts.

Re-Order Point (ROP) = parts lead time

Purchasing Quantity (p) = $j \cdot m$

And: j = rounding number of n (lot size of m units)

$$\text{By: } n = \sqrt{\frac{2Sk}{CImM_{TBF}}} = \sqrt{\frac{2S}{CIm\theta}}$$

The purchasing quantity will be conformed to the EOQ model (or purchasing every $j \cdot \theta$ period). And the new replenishment parts will be purchased at parts lead time but spare parts can be shortage.

CHAPTER 3

RESEARCH METHODOLOGY

The next step after the previous section is to design study and research that aligns with the theoretical framework. This is carried out under the framework of classifying spare parts (components) into eight distinct groups as mentioned in the previous section. The data used to test hypotheses and various concepts are derived from real data on components usage, and simulations are conducted to ensure that the theoretically proposed concepts are accurate and in line with the principles of cost-effective for spare parts management. This will include interview with experts with specialized knowledge in maintenance may also be conducted. The details of the research methodology include the following information:

3.1 Research Design

The research design for this study considers system or machinery that uses spare parts ranging from a small quantity to a large quantity. Therefore, the research design will include the following steps:

1. Grouping the spare parts data based on relevant patterns, such as spare part price (cost), frequent usage speed (movement), and importance (Criticality) to the machinery (or system). This categorization aligns with the concepts discussed in Chapter 2.
2. Classifying the parts into high and low-priced categories, high and low-usage speed categories, and high and low importance categories. These results will categorize the spare parts into eight distinct groups of spare parts as:
 - Fast movement – Much necessity – High cost: (FMH)
 - Fast movement – Much necessity – Low cost: (FML)
 - Fast movement – Less necessity – High cost: (FLH)
 - Fast movement – Less necessity – Low cost: (FLL)
 - Slow movement – Much necessity – High cost: (SMH)
 - Slow movement – Much necessity – Low cost: (SML)
 - Slow movement – Less necessity – High cost: (SLH)
 - Slow movement – Less necessity – Low cost: (SLL)
3. Based on the principles established in step 2, these eight groups of spare parts are further analyzed to determine appropriate inventory levels.
4. Proving the divided lines of the Cost, Movement, and Criticality that are the boundaries of separation between high and low values. This line, when used to

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classify spare parts, will result in finding an appropriate spare parts inventory that is more economical than traditional methods.

5. Testing of the bias of the observed data by histogram graph, kurtosis, and skewness checking.
6. Testing the inventory management system to ensure that will give the real cost savings with cost effectiveness.
7. Conducting simulations to reevaluate the system, using relevant parameters' numbers related to the three main factors.
8. Creating code using Virtual Basic Application (VBA) programming to test data and determine suitable inventory levels.
9. Optionally, interview personnel specializing in maintenance practices or the experts in this field for additional insights. The questionnaire and pilot interview are shown in Appendix D. Factors affecting spare part usage will be investigated from the pilot interviews and used as initial considerations for this study.

These are all steps in the research design for this study. For the details will be explained further in the next issues.

Note: The VBA code creation, this section is provided as an option that can find the right inventory of all types and kinds of parts, including every part's unit price.

3.2 Population and Sample

The samples for this study are the spare parts using in the passenger baggage handling system of the large Airport. By one time sampling amount 285 parts from different types of spare parts out of approximately amount 1,114 parts from all types of spare parts in the system.

However, this populations used for the study will not include spare parts that are breakdown or damaged from various accidents such as car crashes, lightning strikes, electric shorts, etc. It will also not include parts that are structural parts of machines or system such as various supports, steel frames, etc., or components with that are very difficult to failure such as wire way, conduit, electrical wires, electrical cabinet, etc. will not be used for consideration.

This case study will be a one-time sampling, and the sample size is based on the sample size table created by Robert V. Krejcie of the University of Minnesota and Earyle W. Morgan of the University of Texas (1970: 608-609) created the population size table and sample size

came up as Table 3.1.

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Table 3.1 Determining sample size from given population size

Population size (N)	Sample size (s)	Population size (N)	Sample size (s)	Population size (N)	Sample size (s)	Population size (N)	Sample size (s)	Population size (N)	Sample size (s)
10	10	100	80	280	162	800	260	2,800	338
15	14	110	86	290	165	850	265	3,000	341
20	19	120	92	300	169	900	269	3,500	346
25	24	130	97	320	175	950	274	4,000	351
30	28	140	103	340	181	1,000	278	4,500	354
35	32	150	108	360	186	1,100	285	5,000	357
40	36	160	113	380	191	1,200	291	6,000	361
45	40	170	118	400	195	1,300	297	7,000	364
50	44	180	123	420	201	1,400	302	8,000	367
55	48	190	127	440	205	1,500	306	9,000	368
60	52	200	132	460	210	1,600	310	10,000	370
65	56	210	136	480	214	1,700	313	15,000	375
70	59	220	140	500	217	1,800	317	20,000	377
75	63	230	144	550	226	1,900	320	30,000	379
80	66	240	148	600	234	2,000	322	40,000	380
85	70	250	152	650	242	2,200	327	50,000	381
90	73	260	155	700	248	2,400	331	75,000	382
95	76	270	159	750	254	2,600	335	100,000	384

Source: Robert V. Krejcie and Eayrle W. Morgan, (1970)

Table 3.1 has shown the determination of sample size from the given population. This table will be used for determining the sample size of spare parts from the whole spares of this study and to be tested against the established heuristics and inventory models.

3.3 Research Method

Basically, this research study is thought by based on the quantitative concept, and the framework is based on the spare parts classification method. This will result in a total of eight groups of spare parts. then takes each group into the EOQ model and LFL model. The principle of thinking after dividing spare parts is: In the case of expensive parts, parts will be kept as little as possible or as necessary. In cases of necessity to the system, it must have safety stocked. In cases where there is little use, the principle of thought in discrete pattern.

3.4 Research Instrument

This research utilizes data collected in the Computerized Maintenance Management System (CMMS), making it the primary tool for this study. Other tools include a laptop computer with a speed of no less than 3.0 GHz and a minimum RAM of 4 GB. Additionally, there may have the questionnaire to be used for survey conducted with experts in the field of maintenance systems.

3.5 Data Collection

Data collection will take place at a large airport over a one-day period. Since the information has already been gathered in the Computerized Maintenance Management System (CMMS), retrospective data covering a span of 210 months or 17.5 years (September 2006 to March 2024) will be retrieved. The primary focus of data collection will be on the date and time of equipment failure, the quantity of replaced parts, and the part prices. The author has collected part prices and other information, like lead time, etc., from data present in the Operation & Maintenance Manual, asked the holding cost fraction and ordering cost from the experts in the maintenance approach.

For the large airports, there are many related systems such as power system, air conditioning system, airplane parking assistance system, ventilation system, airport security system, fire extinguishing system, fire alarm system, and passenger baggage transport systems, etc. Many costs are required for doing the maintenance actions for these various systems to be in availability operations. One of the major costs is the cost of procuring spare parts for supporting the maintenance activities of those systems. Large airports utilize a lot of spare parts each year. And one of the main problems is determining the level of spare parts inventory that is appropriate for the use. Therefore, as mentioned in Chapter 1 earlier, the main problem in managing the spare parts inventory system is that if there are a lot of spare parts stored, it will cause storage costs, cost of inspection and supervision, cost of depreciation of spare parts, and space for storage. But if there are few or insufficient spare parts stored, there is a risk of spare parts being out of stock and causing the cost of losing opportunities to make a profit from sales or services. In addition, the image and reputation that are damaged by system downtime are also important. For example, a power outage due to a lack of spare parts that need to be replaced in the failure one causes the airport to lose its reputation and lose confidence from airport users or from the passengers, etc.

In this study, a case study of the passenger baggage handling system of a large airport will be considered. To test hypotheses and theories, the passenger baggage conveying system is considered to be one of the largest systems at the airport. There are approximately 2.5-2.6 million parts installed in the system. This type of system is considered a highly complex system, and it is one of the nine necessity systems that airports must have. Airports can lack an air conditioning system, lack of parking assistance system, or lack of the elevator and escalator systems but an airport cannot be without a passenger baggage transport system.

This system has a large number of spare parts types that must be managed, including approximately 1,200 types if you include parts or components that do not frequently fail (or are difficult to fail), such as electrical wires, conduits, ground wires, wire-way, paint for beauty, rust-proof paint, machine frame, support devices, bolts, nuts, etc. In this case study, such spare parts types will be avoided taking these kinds of spare parts into calculation.

A total of 285 examples of components (or spare parts) types are selected from 1,114 component types of the complex system. These examples of component types are used for proving and testing against the models of this study to prove this initiative theory is correct. The selection of component types is done using a one-time sampling method, selecting from equipment that is frequently used or a usage movement factor and the spare part unit cost factor. Whilst the importance (necessity) factor for the system or machine will not be taken into account in the random selection because these elements are based on calculations and will be the result of the random selection of the usage movement factor and cost factor.

The main component types that will be used as data for testing can be divided into three main types of equipment:

1. Mechanical component
2. Electrical and Control component
3. Electro-Mechanical component

After selecting representatives from a random sampling of spare parts types from the entire population. By considering random sampling of spare parts, there will be a slight sampling bias because this random sampling is not 100 percent independent. The movement of spare parts usage will be taken into account as well. As mentioned above, parts that do not have any operating movement cannot be considered because no trends or calculations can be considered. The list of sampling component types below is the examples:

Table 3.2 List of example components used for testing against the model

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts deamand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_s	D	k	m	S	I
No.	Component name	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit
Baht	year	year	year	time per year	unit	unit	Baht	percent			
Mechanical component											
1	Smooth top belt (unit in meter)	3,000	0.164	62.8	0.046	21.95	329.28	1,378	15	30,000	30.0%
2	Rough top belt (unit in meter)	3,758	0.164	70.7	0.085	11.83	177.47	836	15	30,000	30.0%
3	Flat belt 30 Degree KT96A	99,945	0.247	9.6	0.400	2.50	2.50	24	1	30,000	30.0%
4	Flat belt 45 Degree KT96A	122,507	0.247	13.5	0.091	11.00	11.00	148	1	30,000	30.0%
5	Flat belt 60 Degree KT96A	166,587	0.247	10.8	0.207	4.83	4.83	52	1	30,000	30.0%
6	Flat belt 90 Degree KT96A	186,200	0.247	11.9	0.036	27.50	27.50	326	1	30,000	30.0%
7	Spiral belt 45 KT96A (Ht:300 mm)	127,519	0.247	9.0	0.900	1.11	1.11	10	1	30,000	30.0%
8	Spiral belt 90 KT96A (Ht:300 mm)	186,200	0.247	1.8	0.900	1.11	1.11	2	1	30,000	30.0%
9	Spiral belt 90 KT96A (Ht:600 mm)	186,200	0.247	8.3	0.250	4.00	4.00	33	1	30,000	30.0%
10	Merge belt KT263	139,500	0.247	1.3	0.022	46.11	46.11	60	1	30,000	30.0%
11	Divert belt KT263	139,500	0.247	2.0	0.091	11.00	11.00	22	1	30,000	30.0%
12	Bearing (Drive pulley) \varnothing 55 mm.	860	0.082	342.8	0.308	3.25	6.50	1,114	2	5,000	5.0%
13	Bearing (Head/Tail pulley) \varnothing 35 mm.	404	0.082	509.3	0.058	17.39	34.78	8,856	2	5,000	5.0%
14	Take-up Bearing \varnothing 35 mm.	543	0.164	374.2	0.085	11.83	23.67	4,428	2	5,000	5.0%
15	Bearing non housing \varnothing 30 mm.	180	0.041	362.2	0.025	39.78	79.56	14,406	2	2,000	5.0%
16	Bearing non housing \varnothing 35 mm.	204	0.041	233.4	0.015	65.33	130.67	15,250	2	2,000	5.0%
17	Bearing non housing \varnothing 45 mm.	262	0.041	120.2	0.031	32.56	65.11	3,914	2	2,000	5.0%
18	Bearing non housing \varnothing 55 mm.	572	0.041	450.0	0.391	2.56	5.11	1,150	2	2,000	5.0%
19	Drive pulley - \varnothing 185, 35 (SA57)	23,600	0.082	117.7	0.078	12.83	12.83	1,511	1	10,000	10.0%
20	Drive pulley \varnothing 235, 45 (SA67)	27,227	0.082	109.7	0.581	1.72	1.72	189	1	10,000	10.0%
21	Drive pulley - \varnothing 235, 55 (SA77)	30,500	0.082	129.1	0.391	2.56	2.56	330	1	10,000	10.0%
22	End pulley - \varnothing 140, 35 (Head-Tail)	12,600	0.082	164.7	0.037	26.89	26.89	4,428	1	5,000	10.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts deamand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_s	D	k	m	S	I
No.	Component name	Unit Baht	Unit year	Unit year	Unit year	Unit time per year	Unit unit	Unit unit	Unit unit	Unit Baht	Unit percent
23	Return roller - Ø 76, 25	5,436	0.082	3,432.7	0.667	1.50	1.50	5,149	1	10,000	10.0%
24	Snub and Bend pulley - Ø 102, 30	11,000	0.082	173.3	0.026	38.44	38.44	6,662	1	10,000	10.0%
25	Take-up pulley - Ø 140, 35	12,600	0.082	55.1	0.025	40.22	40.22	2,215	1	10,000	10.0%
26	Drive pulley Ø 185, 40 (SA67)	26,000	0.082	189.6	0.600	1.67	1.67	316	1	10,000	10.0%
27	Drive pulley (Queue) Ø 185, 35 (SA57)	23,600	0.082	70.6	0.346	2.89	2.89	204	1	10,000	10.0%
28	Flat drive pulley Inside 30mm (KA37)	52,800	0.247	61.2	0.600	1.67	1.67	102	1	25,000	10.0%
29	Flat drive pulley inside 30mm (SA47)	52,800	0.247	8.0	0.082	12.17	12.17	97	1	25,000	10.0%
30	Flat drive pulley outside 30mm (KA37)	52,800	0.247	21.6	0.202	4.94	4.94	107	1	25,000	10.0%
31	Flat drive pulley outside 30mm (SA47)	52,800	0.247	9.1	0.038	26.67	26.67	243	1	25,000	10.0%
32	Flat tail pulley	46,000	0.247	17.7	0.032	31.06	31.06	549	1	25,000	10.0%
33	Flange with bearing Ø 25 mm.	380	0.082	153.0	0.205	4.89	9.78	748	2	5,000	5.0%
34	Flange with bearing Ø 35 mm.	380	0.082	54.6	0.092	10.83	21.67	592	2	5,000	5.0%
35	Trommellager 25mm with bearing	10,800	0.247	144.5	0.161	6.22	6.22	899	1	30,000	10.0%
36	Trommellager 35mm with bearing	21,500	0.247	67.6	0.340	2.94	2.94	199	1	30,000	10.0%
37	Bearing non housing Ø 25 mm.(power turn)	135	0.041	143.2	0.191	5.22	10.44	748	2	2,000	5.0%
38	Bearing for holder (Power turn)	51	0.041	303.6	0.005	191.22	382.44	58,052	2	2,000	5.0%
39	Upper quick release holder c/w bearing	2,842	0.164	33.6	0.002	479.06	479.06	16,093	1	10,000	10.0%
40	Lower quick release holder c/w bearing	2,842	0.164	33.6	0.003	385.06	385.06	12,933	1	10,000	10.0%
41	Spiral drive pulley inside 30mm (SA47)	51,937	0.247	6.0	1.500	0.67	0.67	4	1	20,000	10.0%
42	Spiral drive pulley inside 30mm (SA57)	53,633	0.247	4.5	2.250	0.44	0.44	2	1	20,000	10.0%
43	Spiral drive pulley outside 30mm (SA47)	52,800	0.247	11.0	0.439	2.28	2.28	25	1	20,000	10.0%
44	Spiral drive pulley outside 30mm (SA57)	52,800	0.247	7.8	0.783	1.28	1.28	10	1	20,000	10.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_s	D	k	m	S	I
No.	Component name	Unit Baht	Unit year	Unit year	Unit year	Unit time per year	Unit unit	Unit unit	Unit unit	Unit Baht	Unit percent
45	Spiral tail pulley	45,853	0.247	10.6	0.247	4.06	4.06	43	1	20,000	10.0%
46	Y-Bearing take-up unit SKF-TU35TF	835	0.041	137.6	0.800	1.25	2.50	172	2	2,000	10.0%
47	Guidance roller	2,857	0.164	4.2	0.025	39.50	39.50	164	1	20,000	10.0%
48	Precision roller \varnothing 65 ,NW=1000 mm	23,650	0.247	3.1	0.038	26.33	26.33	82	1	20,000	10.0%
49	Self Aligning with Spring Ball is the D-nut	180	0.041	23.1	0.188	5.33	5.33	123	1	2,000	10.0%
50	Back up roller \varnothing 65, N=1000 mm	23,500	0.247	3.8	0.047	21.44	21.44	82	1	25,000	10.0%
51	Flange with bearing \varnothing 40 mm.	1,470	0.164	14.5	0.088	11.33	22.67	164	2	10,000	5.0%
52	Grooved ball bearing	2,818	0.082	61.5	0.375	2.67	5.33	164	2	2,000	5.0%
53	Bearing for precision roller	81	0.082	8.2	0.012	80.39	160.78	656	2	2,000	5.0%
54	Roller castor \varnothing 50	2,100	0.247	6.2	0.019	52.67	52.67	328	1	10,000	10.0%
55	Belt tracking station	29,200	0.247	4.5	0.054	18.39	18.39	82	1	30,000	10.0%
56	Friction bearing (Polymer bushing)	225	0.041	9.3	0.018	55.39	55.39	516	1	2,000	5.0%
57	Swing plate	1,800	0.247	13.7	0.084	11.94	11.94	164	1	10,000	5.0%
58	Brass bushing	6,625	0.247	14.6	0.089	11.22	11.22	164	1	10,000	5.0%
59	Distance tube	1,000	0.247	20.5	0.125	8.00	8.00	164	1	10,000	5.0%
60	Shaft for 45 degree merge	4,055	0.247	18.7	0.114	8.78	8.78	164	1	25,000	10.0%
61	Deck Board for Merge Conv.	42,200	0.247	11.9	0.305	3.28	3.28	39	1	40,000	10.0%
62	Hexagon head screw, M8x200 (Galvanised)	152	0.164	52.7	0.321	3.11	3.11	164	1	5,000	5.0%
63	Belt guiding stud	945	0.164	7.0	0.021	46.67	46.67	328	1	5,000	5.0%
64	Pressure spring (long type)	310	0.082	6.5	0.040	25.06	25.06	164	1	2,000	5.0%
65	Tracking station pressure spring (Short)	235	0.082	7.6	0.047	21.44	21.44	164	1	2,000	5.0%
66	Upper nose bar coated 45 Degree	37,500	0.164	5.6	0.068	14.67	14.67	82	1	20,000	10.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_S	D	k	m	S	I
No.	Component name	Unit Baht	Unit year	Unit year	Unit year	Unit time per year	Unit unit	Unit unit	Unit unit	Unit Baht	Unit percent
67	Lower nose bar coated 45 Degree	34,100	0.164	5.6	0.068	14.67	14.67	82	1	20,000	10.0%
68	Activation unit, left	21,355	0.247	8.2	0.118	8.44	8.44	69	1	20,000	10.0%
69	Activation unit, right	20,542	0.247	13.3	0.429	2.33	2.33	31	1	20,000	10.0%
70	Block gasket	521	0.247	123.6	0.038	26.06	26.06	3,220	1	20,000	10.0%
71	Bottom part, relief, back	2,772	0.247	1,288.0	0.400	2.50	2.50	3,220	1	20,000	10.0%
72	Code plate	518	0.247	171.5	0.107	9.39	9.39	1,610	1	20,000	10.0%
73	Con-kit, front, W1000	9,060	0.247	213.1	0.132	7.56	7.56	1,610	1	20,000	10.0%
74	Con-kit, rear, W1000	8,881	0.247	298.8	0.186	5.39	5.39	1,610	1	20,000	10.0%
75	Cover bottom curve 15deg R3000	3,270	0.247	168.0	1.500	0.67	0.67	112	1	20,000	10.0%
76	Cover for cart profile 1250	3,046	0.247	29.6	0.018	54.39	54.39	1,610	1	20,000	10.0%
77	Diverting brush	724	0.247	14.9	0.108	9.28	9.28	138	1	10,000	5.0%
78	Spring l160 for Tilt tray sorter	350	0.247	1,207.5	0.750	1.33	1.33	1,610	1	10,000	5.0%
79	Suspension f.cover back level	385	0.247	133.5	0.083	12.06	12.06	1,610	1	25,000	10.0%
80	T bolt 28/15 special M10*25	64	0.247	5,858.4	1.200	0.83	0.83	4,882	1	10,000	5.0%
81	Tilting device, S2000	22,000	0.247	14.5	0.009	110.94	110.94	1,610	1	40,000	10.0%
82	Tray width=1000, Pitch 1250v	19,460	0.247	13.4	0.008	119.78	119.78	1,610	1	40,000	10.0%
83	Wire loop cart	59,222	0.247	146.4	0.091	11.00	11.00	1,610	1	40,000	10.0%
84	Eccentric ball-and-socket join	3,133	0.247	5.0	0.003	321.50	321.50	1,610	1	10,000	5.0%
85	Support front rear kit	5,262	0.247	852.4	0.529	1.89	1.89	1,610	1	20,000	10.0%
86	Retrofit kit wheel	6,400	0.247	10.3	0.003	312.83	312.83	3,220	1	20,000	5.0%
87	Wheel d90, Blicke 02	2,717	0.247	12.0	0.004	268.50	268.50	3,220	1	10,000	5.0%
88	Threaded bushing M8x012x15 (St)	106	0.247	75.1	0.023	42.89	42.89	3,220	1	10,000	5.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_S	D	k	m	S	I
No.	Component name	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit
		Baht	year	year	year	time per year	unit	unit	unit	Baht	percent
89	Skive D=28 d=8.5 H=4.5	1,240	0.247	77.3	0.024	41.67	41.67	3,220	1	10,000	5.0%
90	Screw UH Ub 8.8 FZB M8x20	106	0.247	19.3	0.006	166.67	166.67	3,220	1	10,000	5.0%
91	Tight - Fitting bolt complete	2,344	0.247	28.0	0.009	114.83	114.83	3,220	1	10,000	5.0%
92	Tooth plate	227	0.247	28.5	0.009	113.11	113.11	3,220	1	25,000	10.0%
93	Activation arm	4,524	0.247	253.1	0.079	12.72	12.72	3,220	1	25,000	10.0%
94	Locking plate	132	0.247	10.1	0.006	159.61	159.61	1,610	1	20,000	10.0%
95	Machaine screw pan head	45	0.247	12.7	0.004	253.78	253.78	3,220	1	10,000	5.0%
96	Lock nut with nylon washer	91	0.247	12.8	0.004	252.11	252.11	3,220	1	10,000	5.0%
97	Stop plate of collision device	2,500	0.247	13.8	0.100	10.00	10.00	138	1	20,000	10.0%
98	Adjustment nut	501	0.247	1,084.2	1.059	0.94	0.94	1,024	1	10,000	5.0%
99	Adjustment screw (short)	522	0.247	1,316.6	1.286	0.78	0.78	1,024	1	10,000	5.0%
100	Transition Belt,L=2147 mm.	5,800	0.247	6.0	0.104	9.61	9.61	58	1	30,000	15.0%
101	Transition Belt,L=2319 mm.	6,150	0.247	5.7	0.099	10.11	10.11	58	1	30,000	15.0%
102	Transition Belt,L=2491 mm.	6,360	0.247	5.7	0.099	10.11	10.11	58	1	30,000	15.0%
103	Belt Induction BW1000 L26 (2634)	37,500	0.247	3.8	0.188	5.33	5.33	20	1	20,000	15.0%
104	Belt Induction BW1000 L37 (3729)	46,500	0.247	4.2	0.212	4.72	4.72	20	1	20,000	15.0%
105	Belt Induction BW1000 L39 (3929)	47,900	0.247	3.8	0.191	5.22	5.22	20	1	20,000	15.0%
106	Belt guide	2,000	0.247	34.4	0.073	13.61	13.61	468	1	20,000	15.0%
107	Drive Roller CPL D90W 1000-50	122,142	0.247	15.6	0.269	3.72	3.72	58	1	30,000	10.0%
108	Drive Roller CPL 80/100 HD G2	86,574	0.247	20.2	0.086	11.67	11.67	236	1	30,000	10.0%
109	Wheel Complete	7,063	0.247	17.3	0.015	66.89	66.89	1,160	1	30,000	10.0%
110	Roller for Induction conv.	96,191	0.247	19.3	0.082	12.22	12.22	236	1	30,000	10.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_S	D	k	m	S	I
No.	Unit Component name	Baht	year	year	year	time per year	unit	unit	unit	Baht	percent
111	Tooth belt 900	5,570	0.247	9.6	0.041	24.67	24.67	236	1	20,000	15.0%
112	Tooth pulley	2,112	0.247	22.6	0.103	9.72	9.72	220	1	30,000	10.0%
113	Rod end bearing for conv. SCF 20ES	697	0.082	31.6	0.184	5.44	10.89	172	2	10,000	5.0%
114	Rod end bearing for conv. SCF 25ES	844	0.082	31.0	0.720	1.39	2.78	43	2	10,000	5.0%
115	Rod end bearing for conv. SAKAC 20M	900	0.082	29.2	0.170	5.89	11.78	172	2	10,000	5.0%
116	Rod end bearing for conv. SAKAC 25M	1,800	0.082	27.6	0.643	1.56	3.11	43	2	10,000	5.0%
117	End bearing for VSC	558	0.082	65.2	0.126	7.92	15.83	516	2	2,000	5.0%
118	Drive bearing for VSC	499	0.082	13.1	0.051	19.72	39.44	258	2	2,000	5.0%
119	Pressing unit for carousel	2,895	0.082	14.3	0.018	54.61	54.61	780	1	5,000	10.0%
120	Stainless steel slat	8,200	0.082	1,698.9	0.231	4.33	4.33	7,362	1	5,000	10.0%
121	Tension Unit	2,680	0.082	14.8	0.019	52.83	52.83	780	1	5,000	10.0%
122	Load Wheel	275	0.082	6.3	0.000	3,507.50	3,507.50	22,086	1	5,000	5.0%
123	Chain Link	900	0.082	14.9	0.002	492.78	492.78	7,362	1	10,000	10.0%
124	Friction belt for drive	9,050	0.164	23.8	0.305	3.28	3.28	78	1	20,000	15.0%
125	Plastic Bumper with Guide Pin	195	0.082	1.2	0.000	5,909.67	5,909.67	7,362	1	5,000	10.0%
126	Chain Link Pin	390	0.164	6.8	0.001	1,086.61	1,086.61	7,362	1	2,000	5.0%
127	Chain Link Pin (Alignment)	426	0.164	309.6	0.042	23.78	23.78	7,362	1	2,000	5.0%
128	Oil Seal AS 45x75x8-NBR (KA37/SA47)	1,100	0.041	29.4	0.024	40.94	40.94	1,205	1	2,000	20.0%
129	Oil Seal BASF65x100x12-NBR (SA67-Outer)	1,340	0.041	128.2	0.048	20.78	20.78	2,664	1	2,000	20.0%
130	Oil Seal B1SF65x94x10/14.5-FKM (SA67-Inner)	3,280	0.041	128.2	0.048	20.78	20.78	2,664	1	2,000	20.0%
Electrical component											
131	Passenger display	15,000	0.247	405.0	1.125	0.89	0.89	360	1	20,000	10.0%
132	Connecting cable 1.5m	1,800	0.082	462.9	1.286	0.78	0.78	360	1	2,000	5.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_S	D	k	m	S	I
No.	Component name	Unit Baht	Unit year	Unit year	Unit year	Unit time per year	Unit unit	Unit unit	Unit unit	Unit Baht	Unit percent
133	Power adapter (IND205 UK)	5,800	0.247	7.0	0.020	51.17	51.17	360	1	20,000	10.0%
134	Half-wave rectifiers 400VAC, 3A	3,350	0.247	72.0	0.200	5.00	5.00	360	1	20,000	10.0%
135	Sensor f/ioc left	15,090	0.247	1.4	0.089	11.28	11.28	16	1	20,000	10.0%
136	Control box key reset 24 VDC	120,750	0.247	14.4	1.800	0.56	0.56	8	1	25,000	10.0%
137	Grounding wire for cart	128	0.247	3,220.0	2.000	0.50	0.50	1,610	1	10,000	5.0%
138	Repeater for profibus	8,400	0.247	25.4	1.059	0.94	0.94	24	1	25,000	10.0%
139	FQ+M 3.0/1.5kW (Drive unit for motor)	143,400	0.247	12.2	0.087	11.44	11.44	140	1	30,000	15.0%
140	PLC battery (for Sorter)	450	0.082	5.14	0.107	9.33	18.67	48	2	500	25.0%
141	PLC/Battery for QCPU	454	0.082	5.11	0.047	21.33	42.67	109	2	500	25.0%
142	PLC battery (for Sorter memory)	450	0.082	5.54	1.385	0.72	1.44	4	2	500	25.0%
143	PLC/Battery for QCPU Gateway	695	0.082	6.00	3.000	0.33	0.67	2	2	500	25.0%
144	PLC/Redundant CPU Module (QCPU)	52,240	0.164	51.63	0.237	4.22	4.22	218	1	20,000	15.0%
145	PLC/Redundant Power Supply Module	52,000	0.164	560.6	2.571	0.39	0.39	218	1	25,000	15.0%
146	417-4H CPU (1.4 Mbyte)	432,723	0.164	18.0	2.250	0.44	0.44	8	1	20,000	15.0%
147	Memory card 5V flash 2 MB/16 bit	14,772	0.164	72.0	9.000	0.11	0.11	8	1	1,000	5.0%
148	PLC Power supply module	13,600	0.164	4,020.0	6.000	0.17	0.17	670	1	20,000	10.0%
149	Sync. Modules for H-system	18,820	0.247	57.6	3.600	0.28	0.28	16	1	25,000	10.0%
150	BUS Cables	68	0.247	14.1	0.014	70.94	70.94	1,000	1	10,000	5.0%
151	Profibus bus connection	1,120	0.247	82.7	0.667	1.50	1.50	124	1	5,000	10.0%
152	Electr.blok ET200S 2XAO	4,812	0.247	7.2	1.800	0.56	0.56	4	1	5,000	10.0%
153	Electronic Module for ET200S 4DI	897	0.247	16.5	0.017	57.83	57.83	956	1	5,000	10.0%
154	Electronic Module for ET200S 4DO	1,221	0.247	16.2	0.026	38.72	38.72	628	1	5,000	10.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_S	D	k	m	S	I
No.	Component name	Unit Baht	year	year	year	time per year	unit	unit	unit	Baht	percent
155	Interface module IM 151-1 for ET200S	8,494	0.247	13.2	0.107	9.39	9.39	124	1	10,000	10.0%
156	Power Module for ET200S	437	0.247	17.0	0.136	7.33	7.33	125	1	10,000	20.0%
157	Power supply 24 VDC 10A 100/240V (Sorter)	1,352	0.247	11.8	0.077	13.06	13.06	154	1	25,000	20.0%
158	4P Plug - in Relay (24VDC)	150	0.247	8.5	0.125	8.00	8.00	68	1	10,000	10.0%
159	Terminal Modules for Power (ET200S)	275	0.247	2,250.0	18.000	0.06	0.06	125	1	10,000	10.0%
160	Terminal Modules for Electronic (ET200S)	508	0.247	889.4	0.529	1.89	1.89	1,680	1	10,000	10.0%
161	Control 2000 CPU (Vert. carousel)	216,000	0.164	49.3	0.474	2.11	2.11	104	1	20,000	15.0%
162	Voltage regulator	1,420	0.164	9.0	2.250	0.44	0.44	4	1	5,000	20.0%
163	Machine Control MIF 2	102,609	0.247	312.0	3.000	0.33	0.33	104	1	25,000	15.0%
164	Operator control panel (Vert. Car)	276,900	0.247	17.5	0.168	5.94	5.94	104	1	20,000	25.0%
165	Light Barrier Transmitter	4,000	0.247	78.0	0.188	5.33	5.33	416	1	25,000	20.0%
166	Current circuit-breaker	3,040	0.082	85.1	1.636	0.61	0.61	52	1	5,000	10.0%
167	Proximity Switch	2,740	0.164	40.7	0.783	1.28	1.28	52	1	5,000	5.0%
168	Limit switch	2,760	0.164	104.0	1.000	1.00	1.00	104	1	5,000	5.0%
169	Automatic cut-out 440V AC 6A 1pole C	2,880	0.164	104.0	0.500	2.00	2.00	208	1	10,000	10.0%
170	Fluorescent Lamp 35 W	145	0.041	45.3	0.621	1.61	1.61	73	1	2,000	20.0%
171	Photoelectric proximity sensor (MU)	4,050	0.164	49.9	0.818	1.22	1.22	61	1	5,000	5.0%
172	Fuse sensor (Fuse metal)	150	0.164	22.3	0.391	2.56	2.56	57	1	2,000	5.0%
173	Thermal protector 125C (FSD)	547	0.164	342.0	6.000	0.17	0.17	57	1	10,000	10.0%
174	Omron Relay G2R-1-SND DC24V	390	0.082	70.6	0.340	2.94	2.94	208	1	2,000	5.0%
175	2P Omron Relay (12VDC 10A)	113	0.164	19.6	0.327	3.06	3.06	60	1	5,000	5.0%
176	2P Omron Relay (24VDC 10A)	113	0.164	36.6	0.305	3.28	3.28	120	1	5,000	5.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_S	D	k	m	S	I
No.	Component name	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit
		Baht	year	year	year	time per year	unit	unit	unit	Baht	percent
177	Fan fot ATR	3,365	0.164	29.3	0.563	1.78	1.78	52	1	10,000	20.0%
178	Optical-Encoder	8,077	0.164	13.0	0.250	4.00	4.00	52	1	10,000	20.0%
179	Lamp glass LED (Pilot lamp)	130	0.019	168.0	6.000	0.17	0.17	28	1	500	5.0%
180	SC5000-1000 (Controller)	439,452	0.247	55.1	1.059	0.94	0.94	52	1	20,000	15.0%
181	DS8110-2100 (Laser Scanner)	550,000	0.247	18.6	0.090	11.17	11.17	208	1	20,000	25.0%
182	Vent. Fan (throughput 230m ³ /h,AC230V)	3,770	0.164	24.5	0.340	2.94	2.94	72	1	10,000	20.0%
183	Vent. Fan (throughput 500m ³ /h,AC230V)	9,992	0.164	17.6	0.429	2.33	2.33	41	1	10,000	20.0%
184	UPS (230V, 1500VA / 865W)	16,500	0.164	5.0	0.155	6.44	6.44	32	1	25,000	15.0%
185	External Battery Pack for UPS	5,228	0.164	5.9	0.164	6.11	6.11	36	1	25,000	25.0%
186	Soft starter (SMC-3 150-C19 NBR)	7,442	0.164	16.8	0.047	21.17	21.17	355	1	20,000	10.0%
187	Soft starter (SMC-3 150-C3 NBD)	6,133	0.164	11.1	0.141	7.11	7.11	79	1	20,000	10.0%
188	Soft starter (SMC-3 150-C9 NBD)	6,800	0.164	12.1	0.046	21.67	21.67	262	1	20,000	10.0%
189	Direct adaptor link	259	0.164	43.9	0.029	34.44	34.44	1,512	1	20,000	5.0%
190	Magnetic Contactor (24VDC Coil)	575	0.082	33.1	0.018	55.17	55.17	1,828	1	20,000	5.0%
191	Magnetic Contactor (1NO,1NC Coil:DC24V)	860	0.082	18.1	0.018	56.28	56.28	1,018	1	20,000	5.0%
192	Connection Block	107	0.164	179.8	0.225	4.44	4.44	799	1	20,000	5.0%
193	Motor Breaker (3P 1.6-2.5A 100kA/400VAC)	1,293	0.082	161.8	0.159	6.28	6.28	1,016	1	20,000	10.0%
194	Motor Breaker (3P 2.5-4A 100kA/400VAC)	1,300	0.082	147.1	0.257	3.89	3.89	572	1	20,000	10.0%
195	Motor Breaker (3P 4.0-6.3A 100kA/400V)	1,350	0.082	102.5	0.500	2.00	2.00	205	1	20,000	10.0%
196	Motor Breaker (3P 6-10A 100kA/415VAC)	1,527	0.082	312.6	0.947	1.06	1.06	330	1	20,000	10.0%
197	Motor Breaker (3P 0.63-1A 50kA/400VAC)	843	0.082	450.0	18.000	0.06	0.06	25	1	20,000	10.0%
198	Motor Breaker (3P 1-1.6A 50kA/400V)	780	0.082	38.7	0.036	27.89	27.89	1,080	1	20,000	10.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_s	D	k	m	S	I
No.	Component name	Unit Baht	year	year	year	time per year	unit	unit	unit	Baht	percent
199	Motor Breaker (3P 6.3-10A 50kA/400V)	916	0.082	33.5	0.086	11.67	11.67	391	1	20,000	10.0%
200	Motor Breaker (3P 1.6-2.5A 50kA/400V)	850	0.082	31.7	0.103	9.72	9.72	308	1	20,000	10.0%
201	Motor Breaker (3P 2.5-4A 50kA/400V)	788	0.082	24.2	0.114	8.78	8.78	212	1	20,000	10.0%
202	Motor Breaker Aux Switches (1 NO+1 NC)	157	0.082	36.2	0.017	58.22	58.22	2,105	1	10,000	5.0%
203	Inverter FC280(5.5KW/3x380-480VAC)	30,000	0.164	8.4	0.168	5.94	5.94	50	1	25,000	10.0%
204	Inverter ACS355 Drives (0.75 KW.)	7,600	0.164	16.6	0.360	2.78	2.78	46	1	25,000	10.0%
205	Inverter (4kW/480V)	21,674	0.247	27.0	9.000	0.11	0.11	3	1	25,000	10.0%
206	Power supply (4.5A,24VDC)	1,724	0.164	18.4	0.102	9.78	9.78	180	1	20,000	15.0%
207	Power supply (14A,24VDC)	6,315	0.164	16.6	0.692	1.44	1.44	24	1	20,000	15.0%
208	Power supply (27A,24VDC)	6,864	0.164	28.5	1.500	0.67	0.67	19	1	20,000	15.0%
209	Power Supply (50A,24VDC)	11,469	0.164	20.6	0.857	1.17	1.17	24	1	20,000	15.0%
210	Power supply (70W AC220/DC24V)	1,938	0.164	16.1	0.234	4.28	4.28	69	1	20,000	15.0%
211	Power supply (100W AC220/DC15V)	2,824	0.164	18.0	1.500	0.67	0.67	12	1	20,000	15.0%
212	Power supply (150W AC220/DC24V)	3,742	0.164	16.5	1.500	0.67	0.67	11	1	20,000	15.0%
213	Power supply (220W AC220/DC24V)	5,583	0.164	18.0	6.000	0.17	0.17	3	1	20,000	15.0%
214	Power supply (350W AC220/DC24V)	6,548	0.164	7.6	0.947	1.06	1.06	8	1	20,000	15.0%
215	CC-Link Remote Input 16 points (7mA)	6,800	0.164	324.0	1.800	0.56	0.56	180	1	20,000	10.0%
216	CC-Link Remote Input 32 points (7mA)	11,990	0.164	111.7	0.621	1.61	1.61	180	1	20,000	10.0%
217	CC-Link Remote Input 32 points (5mA)	4,509	0.164	63.2	0.316	3.17	3.17	200	1	20,000	10.0%
218	CC-Link Remote Output 16 points (7mA)	2,070	0.164	50.4	0.900	1.11	1.11	56	1	20,000	10.0%
219	CC-Link Remote Output 32 points (7mA)	11,990	0.164	231.4	1.286	0.78	0.78	180	1	20,000	10.0%
220	CC-Link Remote Output 32 points (5mA)	3,961	0.164	69.9	0.692	1.44	1.44	101	1	20,000	10.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_S	D	k	m	S	I
No.	Component name	Unit Baht	Unit year	Unit year	Unit year	Unit time per year	Unit unit	Unit unit	Unit unit	Unit Baht	Unit percent
221	Key selector switch, 3-Stay put	480	0.164	316.3	2.571	0.39	0.39	123	1	10,000	5.0%
222	2P Plug - in Relay (230VAC)	139	0.082	14.9	0.621	1.61	1.61	24	1	5,000	5.0%
223	3P Control Relay/AC230V)	356	0.082	18.0	4.500	0.22	0.22	4	1	5,000	5.0%
224	4P Omron Relay (110/ 120 VAC 5A)	630	0.082	18.0	0.300	3.33	3.33	60	1	5,000	5.0%
225	Earth Leakage Relay (AC 110/240V)	5,497	0.164	95.4	0.900	1.11	1.11	106	1	10,000	5.0%
226	Warning Alarm (TypeA)	3,450	0.082	17.2	0.783	1.28	1.28	22	1	5,000	5.0%
227	Warning Alarm (TypeB)	6,625	0.082	21.0	0.333	3.00	3.00	63	1	5,000	5.0%
228	FUSE LINK 80A	479	0.082	137.6	0.429	2.33	2.33	321	1	5,000	5.0%
229	FUSE LINK 160A	554	0.082	49.3	0.333	3.00	3.00	148	1	5,000	5.0%
230	FUSE BASE 160 A (ABB)	1,812	0.082	66.6	0.450	2.22	2.22	148	1	5,000	5.0%
231	Tranciever Sensor	3,209	0.082	346.0	0.065	15.39	15.39	5,325	1	5,000	5.0%
232	Switch disconnect (Type A)	1,641	0.164	1,387.6	0.818	1.22	1.22	1,696	1	10,000	10.0%
233	Switch disconnect (Type B)	1,869	0.164	386.4	0.281	3.56	3.56	1,374	1	10,000	10.0%
234	Computer Controller for VMC800	779,000	0.329	12.0	1.500	0.67	0.67	8	1	50,000	20.0%
235	Illuminated emergency switching head	526	0.041	7.4	0.129	7.72	7.72	57	1	1,000	20.0%
236	Emergency stop switches	825	0.041	61.7	0.643	1.56	1.56	96	1	1,000	10.0%
237	Contact block for emergency switch	80	0.082	10.6	0.186	5.39	5.39	57	1	1,000	10.0%
238	Brake Control (Rectifier)	3,500	0.164	87.5	0.818	1.22	1.22	107	1	20,000	10.0%
239	MCCB (3P 250AF 250AT 35kA/480V)	21,000	0.164	18.0	4.500	0.22	0.22	4	1	20,000	15.0%
240	Shunt trip 380-415V, 50/60Hz	3,025	0.082	9.0	2.250	0.44	0.44	4	1	2,000	10.0%
241	Auxiliary contact 1No/1NC	930	0.082	9.0	2.250	0.44	0.89	4	2	2,000	5.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_S	D	k	m	S	I
No.	Component name	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit
		Baht	year	year	year	time per year	unit	unit	unit	Baht	percent
Electro-Mechanical component											
242	Drum Motor (Weighted Conveyor)	94,113	0.247	17.8	0.049	20.22	20.22	360	1	25,000	15.0%
243	Weight scale	75,000	0.247	432.0	1.200	0.83	0.83	360	1	40,000	20.0%
244	Gear motor 0.75 kW (i=7.28)	102,950	0.164	36.0	0.168	5.94	5.94	214	1	20,000	10.0%
245	Gear motor 0.75 kW (i=8.64)	102,950	0.164	34.4	0.818	1.22	1.22	42	1	20,000	10.0%
246	Gear motor 0.75 kW (i=9.23)	102,950	0.164	41.0	1.000	1.00	1.00	41	1	20,000	10.0%
247	Gear motor 0.75 kW (i=10.80)	70,750	0.164	18.0	2.571	0.39	0.39	7	1	20,000	10.0%
248	Gear motor 0.75 kW (i=12.10)	70,750	0.164	67.4	0.462	2.17	2.17	146	1	20,000	10.0%
249	Gear motor 0.75 kW (i=14.24)	70,775	0.164	68.4	3.600	0.28	0.28	19	1	20,000	10.0%
250	Gear motor 0.75 kW (i=16.47)	70,750	0.164	57.1	0.783	1.28	1.28	73	1	20,000	10.0%
251	Gear motor 0.75 kW (i=17.62)	70,750	0.164	32.7	1.636	0.61	0.61	20	1	20,000	10.0%
252	Gear motor 0.75 kW (i=20.33)	65,893	0.164	12.0	6.000	0.17	0.17	2	1	20,000	10.0%
253	Gear motor 1.1 kW (i=7.28)	114,150	0.164	21.0	3.000	0.33	0.33	7	1	25,000	10.0%
254	Gear motor 1.1 kW (i=9.23)	79,150	0.164	17.2	0.783	1.28	1.28	22	1	25,000	10.0%
255	Gear motor 1.1 kW (i=14.24)	76,750	0.164	12.0	6.000	0.17	0.17	2	1	25,000	10.0%
256	Gear motor 1.5 kW (i=10.03)	88,450	0.164	12.0	0.750	1.33	1.33	16	1	40,000	10.0%
257	Gear motor 1.5 kW (i=12.96)	88,450	0.164	2.0	2.000	0.50	0.50	1	1	40,000	10.0%
258	Gear motor 1.5 kW (i=13.73)	64,605	0.164	66.0	3.000	0.33	0.33	22	1	40,000	10.0%
259	Gear motor 2.2 kW (i=8.69)	139,150	0.164	18.0	18.000	0.06	0.06	1	1	40,000	10.0%
260	Gear motor 2.2 kW (i=10.03)	139,150	0.164	30.9	2.571	0.39	0.39	12	1	40,000	10.0%
261	Gear motor 2.2 kW (i=11.03)	139,450	0.164	18.0	9.000	0.11	0.11	2	1	40,000	10.0%
262	Gear motor 2.2 kW (i=15.60)	139,500	0.164	4.5	4.500	0.22	0.22	1	1	40,000	10.0%
263	Gear motor 2.2 kW (i=20.37)	139,125	0.164	10.3	2.571	0.39	0.39	4	1	40,000	10.0%

Table 3.2 List of example components used for testing against the model (Cont.)

Variable		Part unit cost	Lead time	MTBF	System MTBF	System Failure rate	Spare parts demand	Total parts installed in the system	Quantity of each change	Purchasing cost per order	Holding cost fraction
Symbol/Variable abbr.		C	L	M_{TBF}	θ	λ_s	D	k	m	S	I
No.	Component name	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit	Unit
		Baht	year	year	year	time per year	unit	unit	unit	Baht	percent
Electro-Mechanical component											
264	Gear motor 2.2 kW (i=23.33)	100,800	0.164	36.0	6.000	0.17	0.17	6	1	40,000	10.0%
265	Gear motor 3 kW (i=9.44)	179,200	0.164	14.4	3.600	0.28	0.28	4	1	45,000	10.0%
266	Gear motor 3 kW (i=12.07)	120,950	0.164	24.6	0.947	1.06	1.06	26	1	45,000	10.0%
267	Gear motor 3 kW (i=13.76)	120,950	0.164	22.5	4.500	0.22	0.22	5	1	45,000	10.0%
268	Gear motor 3 kW (i=15.28)	128,450	0.164	15.4	2.571	0.39	0.39	6	1	45,000	10.0%
269	Gear motor 3 kW (i=18.42)	128,450	0.164	3.6	3.600	0.28	0.28	1	1	45,000	10.0%
270	Gear motor 3 kW (i=20.99)	128,450	0.164	45.0	1.800	0.56	0.56	25	1	45,000	10.0%
271	Gear motor 3 kW (i=32.38)	128,450	0.164	32.7	0.818	1.22	1.22	40	1	45,000	10.0%
272	Gear motor 4 kW (i=15.28)	135,800	0.164	12.9	2.571	0.39	0.39	5	1	50,000	10.0%
273	Gear motor 4 kW (i=18.42)	135,800	0.164	18.0	6.000	0.17	0.17	3	1	50,000	10.0%
274	Gear motor 4 kW (i=20.99)	120,450	0.164	12.0	6.000	0.17	0.17	2	1	50,000	10.0%
275	Gear motor 4 kW (i=25.07)	120,450	0.164	54.0	6.000	0.17	0.17	9	1	50,000	10.0%
276	Gear motor 4 kW (i=28.41)	120,450	0.164	29.1	0.429	2.33	2.33	68	1	50,000	10.0%
277	Gear motor 4 kW (i=32.38)	120,450	0.164	36.0	18.000	0.06	0.06	2	1	50,000	10.0%
278	Multisuspension linearmotor	29,168	0.247	23.7	0.171	5.83	5.83	138	1	20,000	5.0%
279	Linearmotor with Heat sink	117,370	0.247	31.1	0.225	4.44	4.44	138	1	25,000	10.0%
280	FQ Motor 3.0/1.5kW	143,400	0.247	12.2	0.087	11.44	11.44	140	1	30,000	10.0%
281	Gear motor 0.75kW (i=6.80)(RHS) - VSC	69,950	0.164	20.3	1.125	0.89	0.89	18	1	25,000	10.0%
282	Gear motor 0.75 kW (i=6.80)(LHS) - VSC	69,950	0.164	18.0	3.000	0.33	0.33	6	1	25,000	10.0%
283	Gear motor drive arm 1.5 kW (i=22.66)	151,000	0.164	43.0	1.000	1.00	1.00	43	1	35,000	10.0%
284	Disc Brake Complete BMGI Vb 230VAC	27,917	0.123	2,270.6	2.571	0.39	0.39	883	1	10,000	15.0%
285	Disc Brake Complete BMGI Vb 400VAC	24,500	0.123	472.7	0.947	1.06	1.06	499	1	10,000	15.0%

3.6 Statistical Data Analysis

The statistical analysis of this study is not highly complex as the spare parts data has been collected and categorized beforehand. Therefore, using statistics for analysis the inventory is straightforward. Statistical analysis will employ two types of distributions:

1. Utilizing statistics with a Normal distribution for analyzing components (spare parts) with usage exceeding 5 units per year, considering it as continuous usage.
2. Utilizing statistics with a Poisson distribution for analyzing components (spare parts) with usage not exceeding 5 units per year, considering it as intermittent (or non-continuous) usage.
3. Bias testing of observed data uses a histogram to perform a plot and see what pattern this data captures. It also uses measures of skewness and kurtosis of said data. This includes measuring the average and variance of this data as well.
4. To examine the hypothesis, three questions were asked as presented in Chapter 1. The scatter plot, R-Square statistics, and regression analysis (Linear and non-linear equation) may be used to test the relationship between related variables. The test consists of the following assumptions:
 - There is a negative variable relationship between the spare parts unit price and the number of spare parts used.
 - There is a positive variable relationship between the importance of spare parts required in the system and the number of spare parts used.
 - There is a positive variable relationship between the spare parts unit price and the importance of spare parts required in the system.

CHAPTER 4

ANALYSIS RESULTS

According to this study, three main issues will be and five study cases are exploited to support the results and models. All study cases are based on the data and information about real equipment and machinery observed on-site. Some data and values come from equipment specifications and supplier recommendations. Any values (that cannot be collected from real data) are simulated under cognitive thinking and previous approaches related to this study. Some data and information are from interviews with experts and specialists with much expertise in maintenance approaches. Most of the spare parts cost comes from gathering real purchasing but some of them come from searching from the internet. However, most of this study's data, information, and any values are confirmatory observations. These are based on an entirely theoretical basis and must be proved by a technical background before being used as the input data. Therefore, these data, information, and values will provide confidence and certainty.

As mentioned in the previous paragraph. The theoretical and model proof-of-concept consists of five case studies, which test the model and the classification of parts. The consideration of test results consists of three parts:

1. Basic statistics of data and information to use
2. Hypothesis testing
3. Case studies to verify and prove the initiative models and theory

All five cases include verification and testing as follows:

- Case 1: The Classification of the Necessity Factor (or Criticality).
- Case 2: The classifying of high and low-cost spare parts for fast-moving items (or frequently used spare parts).
- Case 3: The classifying of high and low-cost spare parts for slow moving items (or scarcely used spare parts)
- Case 4: The proving of the Extension EOQ model.
- Case 5: Classifying of spare parts (MRO) for 8 baskets inventory system

Note: Five case studies will be exploited to validate and prove the spare parts inventory model of the eight baskets inventory system. The use of mathematical results and graphs to show the accuracy of the said models. Additionally, there is also a section on some of the device calculations of the inventory model and its safety stock examples that show how the model works for real-world applications. This includes considering the appropriateness of using the eight inventory models in an actual use and its applications.

4.1 Basic statistics of data and information to use

First of all, the basic statistics of data, information, and values shall be tested according to theoretical testing methods. For this study, the 3 main factors are tested, and the statistics value are shown as follows:

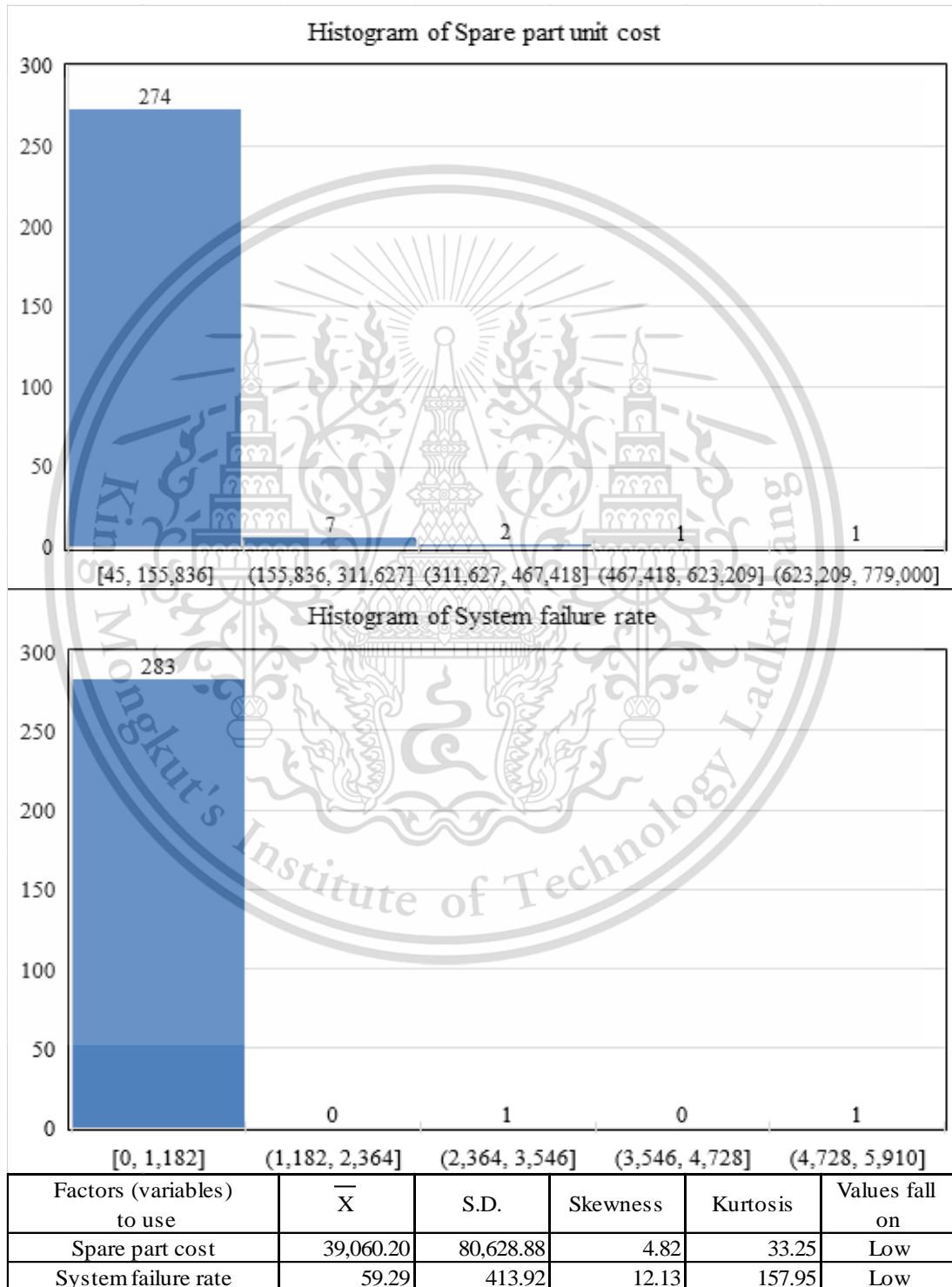


Figure 4.1 Histogram of spare part unit cost and System failure rate

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Note: The necessity (criticality) factor variable is from the calculation values in ratios, not raw data collected from actual observational data. Therefore, it cannot be used for consideration.

According to Figure 4.1, the observed values for both spare parts cost and failure rate most fall into the low range. This value is confirmed by the skewness value of the histogram as shown in Figure 21. It can be seen that there is a right skew (or most of the values appear on the left side of the graph). Although the distribution of values is quite small (Most of them swarm with low values) but some values extremely jump out of the group quite high, therefore the standard deviation is also very high. As for the kurtosis value of the data obtained from the test, it can be seen that it has a relatively high value, indicating that the value of the data is highly clustered.

However, in analyzing the results of the warehouse inventory system, such values cannot be eliminated like the analysis in the case of using questionnaires. Because the results of high values that jump out of the group will be analyzed, maintenance may not be correct or do not meet engineering principles. What is important besides the reasons above? The consideration of classifying spare parts into eight groups, if such information is not taken into account, may cause the overall picture of the groups and spare part type to be changed.

4.2 Hypothesis test results

According to Chapter 1, the hypothesizes were issued, and the testing of the hypothesis are 3 items as follows:

1. There is a negative variable relationship between the spare parts unit price and the number of spare parts used.
2. There is a positive variable relationship between the necessity of spare parts required in the system and the number of spare parts used.
3. There is a positive variable relationship between the spare parts unit price and the importance of spare parts required in the system.

This is because the information on the necessity for spare parts cannot be taken into account as discussed in the previous section. Therefore, there is only one hypothesis left to test as follows: There is a negative variable relationship between the spare parts unit cost and the amount of spare parts used (or movement factor). And, from the test, the results were as follows (as shown in Figure 4.2, 4.3, and 4.4):

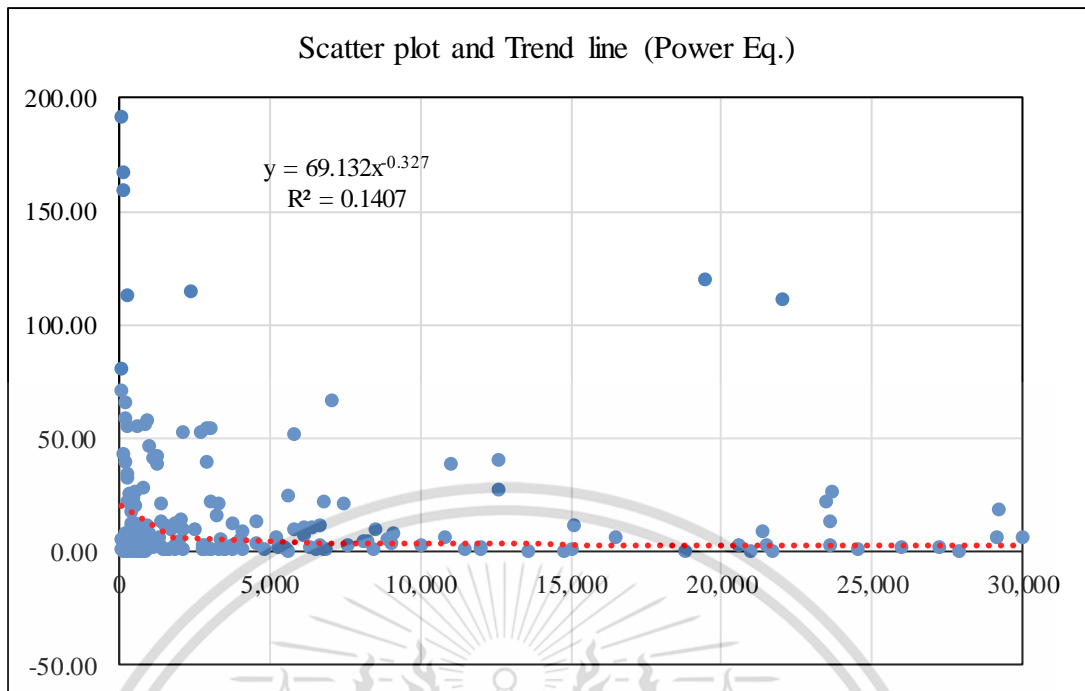


Figure 4.2 Scatter plot and Trend line between spare part unit cost and failure rate (Power equation)

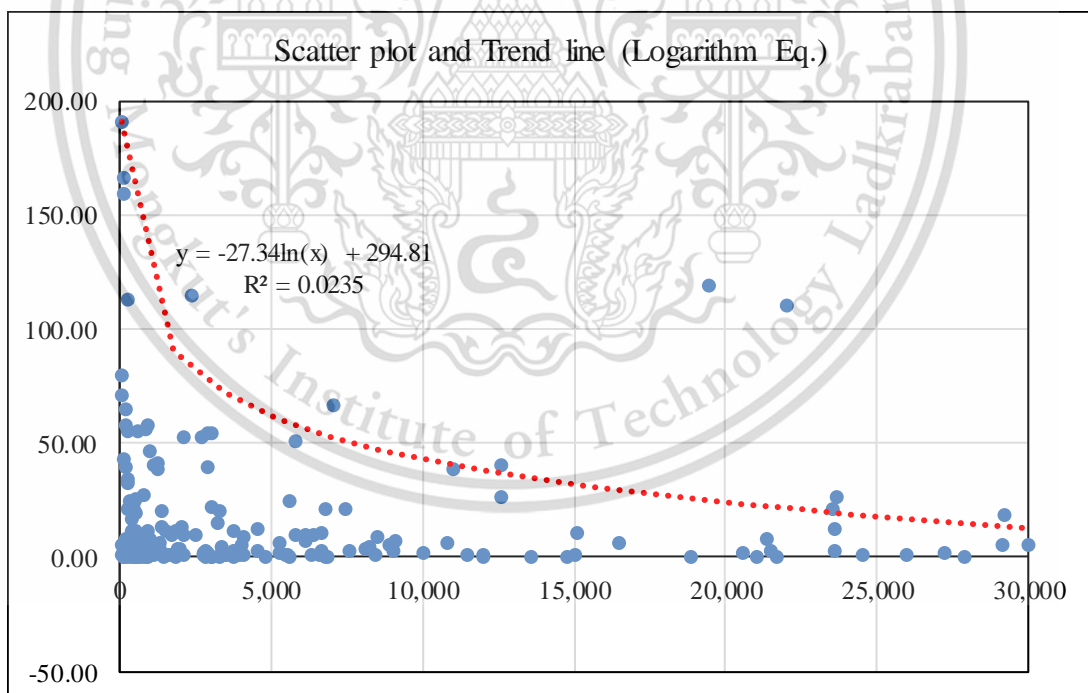


Figure 4.3 Scatter plot and Trend line between spare part unit cost and failure rate (Logarithm equation)

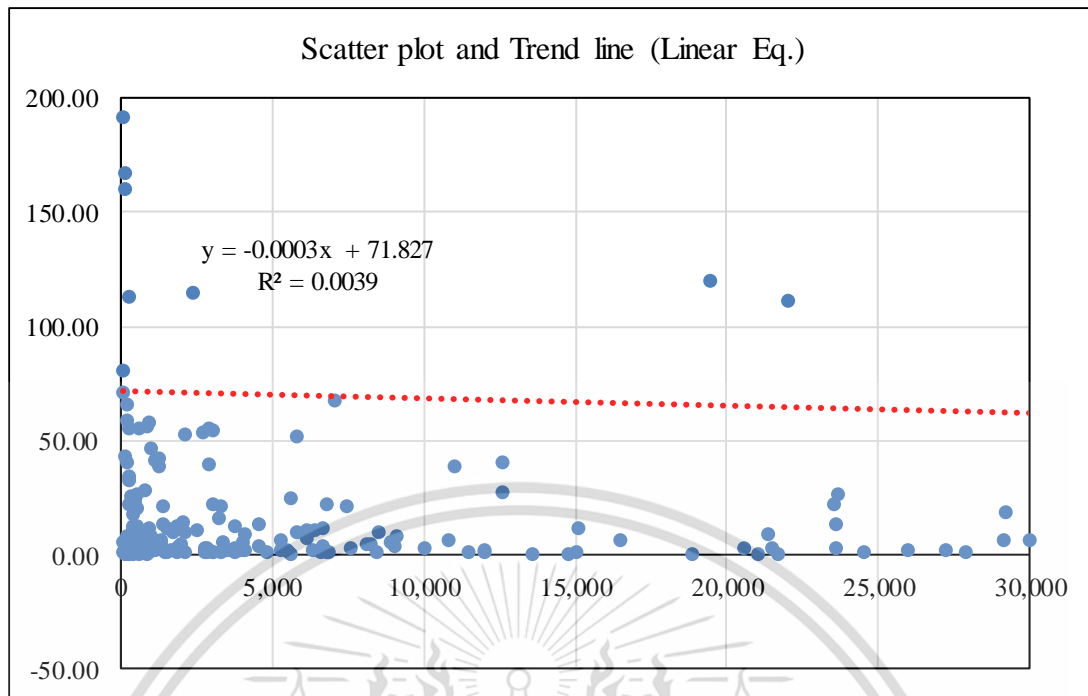


Figure 4.4 Scatter plot and Trend line between spare part unit cost and failure rate (Linear equation)

The graphs shown above are a scatterplot between the price of spare part per unit and the failure rate of various parts in the machines. This section shows a graph as a form of finding the relationship between the price of spare parts per unit and the failure rate by finding a relationship as a linear and non-linear relationship. The results and explanations show as the below paragraphs:

- Figure 4.2 is the power equation (non-linear). An equation shows the relationship between spare part unit cost and failure rate in Figure 4.2. It is a model that says when the price of spare parts is high, the failure rate will be low, while when the price of spare parts is low, the failure rate will be high when looking at only the relationship in an equation. Or, it can be concluded that negative relationship. However, when looking at other values like the R-squared value, it was found to be very small, indicating this equation was only able to explain approximately 14 percent of the results. According to statistical principles, the R-squared should be greater than 90 percent for the correlation equation to be considered to explain the results. Therefore, in this case, it cannot be considered that the price of spare parts has an effect on the failure rate of parts in the machine. Such cases are similar to Figure 4.3 and Figure 4.4.

- Figure 4.3 is the logarithm equation (non-linear). Or, it can be concluded that negative relationship. This cannot be exploited to explain the relationship same as Figure 4.2. The reason was given in prior.
- Figure 44 is the linear equation. Or, it can be concluded that negative relationship. This cannot be exploited to explain the relationship same as figure 4.2. The reason was given in prior.

Anyhow, the first equation (the power equation) appears to be the one that describes the relationship better than when compared to the other equations based on the value R-Square but the statistical principles still consider that there is no relationship, which is consistent with maintenance principles because the replacement of spare parts for broken parts in machines normally does not take into account the price of the replacement parts but the consideration will be given to the need for replacement and the impact on the production rate of the machine or system rather than considering the price of spare parts. If the price of spare parts is high but it is necessary for production to continue, and to be able to generate more income from production than the price of spare parts that must be paid, it is considered something that the manufacturer or factory should do.

4.3 Case study

Case study 1: The Classification of the Necessity Factor (or Criticality)

The necessity factor can be implied as a spare part being critical. If the spare part is very necessary for the system, then it is implied as criticality, or if the spare part is less necessary for the system, then it is implied as non-criticality. The necessity factor is based on the ratio between production loss cost (or loss of opportunity to make profitability during maintenance downtime) compared against part(s) holding cost. If the value is greater than one, then the part can be implied as a critical part. Otherwise, if the value is less than one, then that part can be implied as a non-critical part. Example equipment of case study 1 is the components of the baggage automatic sorting system. There are four components types which are the case studies:

1. Linear motor, this part is used to act as a driver for the tray of the automatic sorter system so that the tray will move along slide rails that have the characteristics of a loop guide rail.
2. Wire Loop Cart, this component is used for being the basement of sorter tray, this equipment looks quite the bogie in the looping equipment in the baggage automatic sorting machine.

3. Cover bottom curve 15deg, this component is used for protecting the dust and the dirtiness from surrounding area from bottom side.
4. Lamp glass LED (pilot lamp), this component is the lamp (or lighting) which is used for indicating the existence of electricity passing through the Motor Control Panel (MCP).

Table 4.1 Production loss cost

Variable	unit	Component type			
		Linear motor	Wire loop cart	Cover bottom curve	Lamp glass LED
Production Rate (P_R)	bag per day	45,200	45,200	45,200	45,200
Lead Time (L)	day	90	90	90	7
Amount of components in system (k)	unit	138	1,610	1,610	28
Affection Rate (p_{aff})	percent	0.1812%	0.0155%	0.0001%	0.0001%
Profit per bag (π)	Baht	20	20	20	20
Production loss cost (P_{LC})	Baht	147,424	12,611	81	6

Table 4.2 Inventory cost

Variable	unit	Component type			
		Linear motor	Wire loop cart	Cover bottom curve	Lamp glass LED
Material (or Spare Part) Cost (C)	Baht	117,370	59,222	3,270	120
Number of parts for each change (m)	each	1	1	1	1
Percentage of Holding Cost (I)	percent (per year)	10.0%	10.0%	10.0%	5.0%
System Mean Time Between Failures (θ)	year	0.225	0.091	1.50	6.00
Total Holding Cost (TH_C)	Baht (per year)	2,641	539	491	36

Note: All parts are the components of the baggage automatic sorting machine used for sorting the baggage automatically operated.

Table 4.3 Spare parts classification (Necessity factor)

Component type	Production loss cost (PL_C)	Total holding cost (TH_C)	Ratio of PL_C to TH_C (R_{PH})	Necessity	
				Much	Less
Linear motor	147,424	2,641	55.83	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Wire loop cart	12,611	539	23.40	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Cover bottom curve	81	491	0.17	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Lamp glass LED	6	36	0.18	<input type="checkbox"/>	<input checked="" type="checkbox"/>

According to Table 4.3, the linear motor and wire loop cart are necessary, and it can be concluded that these parts are critical because the production loss cost is greater than the total holding cost. Contrary, the cover bottom curve and lamp glass LED are less-necessary parts, it can be concluded that these parts are non-critical because the production loss cost is less than the total holding cost. Basically, spare parts of the cover for the bottom and lamp glass LED can be allowed to be in shortage if there are breakdowns, and these parts can wait until the new parts arrive on site (no safety stock). But linear motors and wire loop carts, cannot be allowed. Thus, spare parts for the linear motor and wire loop cart are provided to meet their demand (or failure rate), and safety stock must be provided to meet its failure rate and variation.

Case study 2: The classifying of high and low cost for fast moving items

According to the cost factor, the classifying of spare parts is based on the comparison between the total inventory cost of LFL model and EOQ model. The break-even point (C^*) is the separation line between high and low-cost materials and it can be implied as the boundary of high and low cost. If a part is implied as high-cost material then LFL model is suitably applied to control that part. Otherwise, if a part is implied as low-cost material then the general EOQ model is suitably applied to control that part. There are four components types which are the case studies as:

1. Gear motor 1.5 kW (or 2 horsepower) with a gearing ratio of $i = 12.96$, this component is used to create the driving power to conveyor lines.
2. Gear motor 1.5 kW (or 2 horsepower) with a gearing ratio of $i = 13.73$, this component is used to create the driving power to conveyor lines.
3. Gear motor 4 kW (or 5 horsepower) with a gearing ratio of $i = 25.07$, this component

This material is used to create the driving power to conveyor lines and for commercial use.

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4. Gear motor 4 kW (or 5 horsepower) with a gearing ratio of $i = 28.41$, this component is used to create the driving power to conveyor lines.

Table 4.4 Component details and Variables

Variable	Unit	Component name			
		Gear motor 1.5 kW (Gearing ratio: $i=12.96$)	Gear motor 1.5 kW (Gearing ratio: $i=13.73$)	Gear motor 4 kW (Gearing ratio: $i=25.07$)	Gear motor 4 kW (Gearing ratio: $i=28.41$)
Part unit cost (C)	Baht	88,450	88,450	120,450	120,450
Amount of parts in the system (k)	each	1	22	9	68
Lead time (L)	year	0.164	0.164	0.164	0.164
Amount pieces per one change (m)	each	1	1	1	1
Mean time between failures (M_{TBF})	year	2.0	66.0	54.0	29.1
Ordering cost (S)	Baht	40,000	40,000	50,000	50,000
Fraction of holding cost (I)	% of unit cost	10%	10%	10%	10%
Separation line (C^*)	Baht	100,000.0	66,666.7	41,666.7	583,333.3

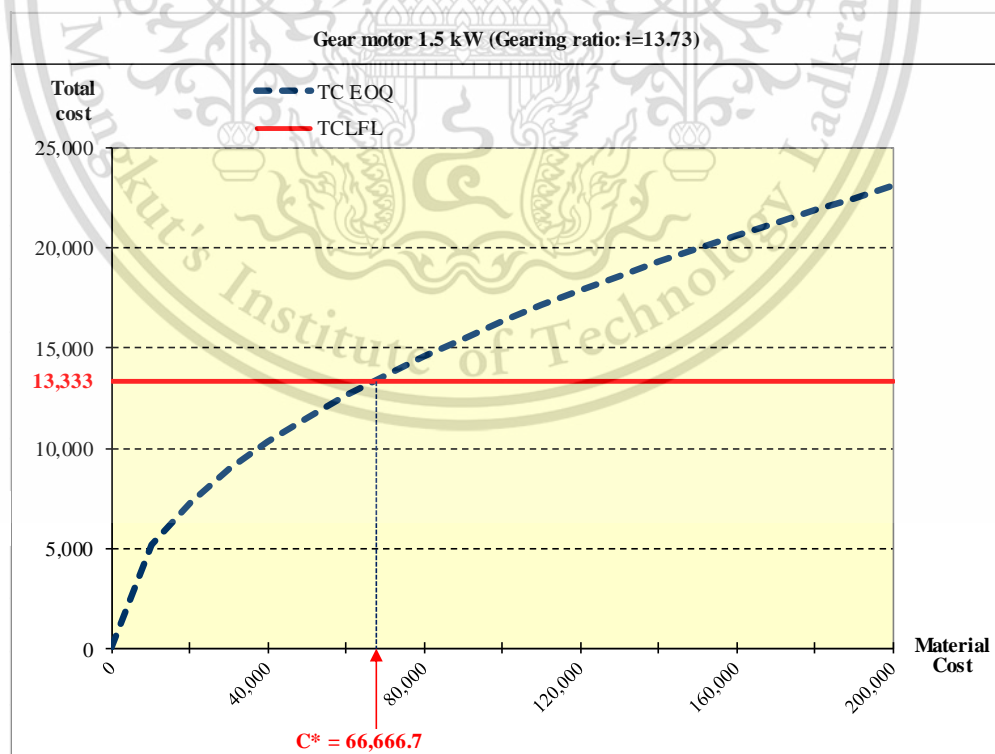


Figure 4.5 Plotting (simulation) of Total inventory cost (for Gear motor 1.5 kW with Gearing ratio of $i = 13.73$) against spare part unit cost (C).

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Table 4.5 Simulation of total inventory cost (for Gear motor 1.5 kW with Gearing ratio of $i = 13.73$) and comparison between General EOQ model and LFL model.

	Material unit cost (C)	TC_{EOQ}	TC_{LFL}		Material unit cost (C)	TC_{EOQ}	TC_{LFL}
		0	0		13,333		100,000
	10,000	5,164.0	13,333.3		110,000	17,127.0	13,333.3
	20,000	7,303.0	13,333.3		120,000	17,888.5	13,333.3
	30,000	8,944.3	13,333.3		130,000	18,619.0	13,333.3
	40,000	10,328.0	13,333.3		140,000	19,321.8	13,333.3
	50,000	11,547.0	13,333.3		150,000	20,000.0	13,333.3
	60,000	12,649.1	13,333.3		160,000	20,655.9	13,333.3
Break-even point (C^*)	66,667	13,333.3	13,333.3		170,000	21,291.6	13,333.3
	70,000	13,662.6	13,333.3		180,000	21,908.9	13,333.3
	80,000	14,605.9	13,333.3		190,000	22,509.3	13,333.3
	90,000	15,491.9	13,333.3		200,000	23,094.0	13,333.3

Table 4.6 Comparison of Total inventory cost between the General EOQ model and LFL model

Cost	Unit	Component name							
		Gear motor 1.5 kW (Gearing ratio: $i=12.96$)		Gear motor 1.5 kW (Gearing ratio: $i=13.73$)		Gear motor 4 kW (Gearing ratio: $i=25.07$)		Gear motor 4 kW (Gearing ratio: $i=28.41$)	
		EOQ	LFL	EOQ	LFL	EOQ	LFL	EOQ	LFL
Failure rate (λ)	units/year	0.50	0.50	0.02	0.02	0.02	0.02	0.03	0.03
System failure rate (λ_s)	units/year	0.50	0.50	0.33	0.33	0.17	0.17	2.33	2.33
Quantity (Q^*)	unit	2.1	1	1.7	1	1.2	1	4.4	1
Actual Purchasing (j)	unit	2	1	2	1	1	1	4	1
Total Ordering Cost	Baht	10,000	20,000	6,667	13,333	8,333	8,333	29,167	116,667
Total Holding Cost	Baht	8,845	0	8,845	0	6,023	0	24,090	0
Total Cost (Inventory Cost)	Baht	18,845	20,000	15,512	13,333	14,356	8,333	53,257	116,667

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Observation from Table 4.6, the actual quantity purchased for gear motor 4 kW. with a gearing ratio $i = 25.07$ is 1 unit when replacing broken parts in the machine. So, it should not appear that a spare part holding cost appears because one spare unit is already being replaced on a machine and there should be no more spare parts being held. Observations tell us that in cases where parts are used slowly, using the EOQ model calculations would not make sense.

Table 4.7 Spare parts classification (fast moving items)

Component	Separation Line (C^*)	Spare part unit cost (C)	Type of part		Component is fitted to	
			Low cost	High cost	EOQ	LFL
Gear motor 1.5 kW (Gearing ratio: $i=12.96$)	100,000	88,450	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Gear motor 1.5 kW (Gearing ratio: $i=13.73$)	66,667	88,450	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Gear motor 4 kW (Gearing ratio: $i=25.07$)	41,667	120,450	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Gear motor 4 kW (Gearing ratio: $i=28.41$)	583,333	120,450	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

According to Table 4.7, the separation line is the boundary between high and low-cost spare parts. For this study, the gear motor 1.5 kW. with gearing ratio 12.96, and gear motor 4 kW. with gearing ratio 28.41 can be implied as a low-cost spare part which is suitably applied to the general EOQ model for controlling its inventory. Otherwise, the gear motor 1.5 kW. with gearing ratio 13.73, and gear motor 4 kW. with gearing ratio 25.07 can be implied as a high-cost spare part that is suitably applied to the LFL model for controlling its inventory.

Case study 3: The classifying of high and low cost for slow moving items

Similar to the case of fast-moving items, if a part is implied as high-cost material then LFL model is suitably applied to control that part. Otherwise, if a part is implied as low-cost material then the extension EOQ model is suitably applied to control that part. The following are the classifying of a cost factor. However, the separation line (or break-even point) for slow-moving items is quite a little different from fast-moving items. Because the cognitive thinking between fast and slow-moving items about the separation line is not similar (for more details and explanations, see Chapter 2 and Appendix 3).

From the previous case study, it can be seen that there are slight discrepancies in the calculations with the EOQ model. The results are not as expected as in the case of gear motor 4 kW. with a gearing ratio $i = 25.07$, this was pointed out in the prior case.

Consequently, the following case study will serve as a testament to the validity of this study, which will be referred to as the Extension of EOQ model. There are six components types which are the case studies as:

1. PLC Battery (for Sorter CPU), It is a part to be exploited to provide the backup power to the memory inside the CPU (PLC inside the central control panel) of an automatic baggage sorting system. In this case, the backup memory needs to be backed up for at least half an hour, this will be used in the event of a power outage. Another reason for having this part is to reduce electrical ripples or reduce damage to the circuit from electrical harmonics.
2. PLC Battery for QCPU gateway, it is a part to be exploited to provide the backup power to the memory inside the CPU (Gateway PLC inside the main control panel, in the main control room) of the data transmission system for the main passage that connects to the passenger baggage conveyor system and other related systems. In this case, the backup memory needs to be backed up for at least half an hour, this will be used in the event of a power outage. Another reason for having this part is to reduce electrical ripples or reduce damage to a circuit from electrical harmonics.
3. Inverter (4 kW./480V.), this part is a device that drives the motor used for driving the baggage conveyor belt before entering the automatic sorting system. By changing the frequency so that the motor rotates fast or slow at a specified pace to coordinate with the automatic sorting system.
4. Memory card 5V flash 2MB/16 bit, this part is a device used as a secondary memory for an automatic sorting system. This part looks like a card used for inserting into the slot (inside the PLC module) but is not like a normal memory card.
5. 417-4H CPU (1.4Mbyte), this part is the CPU central processing unit for the automatic sorting system located in the PLC of main control panel. Duty is to receive orders from the central control system to process baggage sorting.
6. Control 2000 CPU (for vertical carousel), this part is the central processing system (CPU) of the early baggage claim system, where passengers check in 4 hours before the flight departs (the baggage arrives in the baggage locker early, it is called a vertical carousel). This part processes and allocates time to notify the central control system when baggage is going in and out.

Table 4.8 Component details and Variables

Variable	Unit	Component name					
		PLC Battery (for Sorter CPU)	PLC Battery for QCPU Gateway	Inverter (4kW/480V)	Memory card 5V flash 2 MB/16 bit	417-4H CPU (1.4 Mbyte)	Control 2000 CPU (Vert. carousel)
Part unit cost (C)	Baht	450	695	21,674	14,772	432,722.5	216,000.0
Amount of parts in the system (k)	each	4	2	3	8	8	104
Lead time (L)	year	0.082	0.082	0.247	0.164	0.247	0.164
Amount pieces per one change (m)	each	2	2	1	1	1	1
Mean time between failures (M_{TBF})	year	5.5	6.0	27.0	72.0	18	49.3
System mean time between failures (θ)	year	1.385	3.000	9.000	9.000	2.25	0.474
System failure rate (λ_s)	time per year	0.722	0.333	0.111	0.111	0.444	2.111
Ordering cost (S)	Baht	500	500	25,000	1,000	20,000	20,000
Fraction of holding cost (I)	% of unit cost	25%	25%	10%	5%	15%	15%
Separation line (C^*)	Baht	1,444.4	666.7	55,555.6	4,444.4	118,518.5	562,963.0

Table 4.9 Comparison (of Total inventory cost) between the Extension EOQ model and LFL model

Cost	Unit	Component name											
		PLC Battery (for Sorter CPU)		PLC Battery for QCPU Gateway		Inverter (4kW/480V)		Memory card 5V flash 2 MB/16 bit		417-4H CPU (1.4 Mbyte)		Control 2000 CPU (Vert. carousel)	
		EOQ	LFL	EOQ	LFL	EOQ	LFL	EOQ	LFL	EOQ	LFL	EOQ	LFL
Failure rate (λ)	units/year	2.9	2.9	0.7	0.7	0.3	0.3	0.9	0.9	3.6	3.6	219.6	219.6
System failure rate (λ_s)	units/year	0.72	0.72	0.33	0.33	0.11	0.11	0.11	0.11	0.44	0.44	2.11	2.11
Total lot (n)	unit	1.79	1	0.98	1	1.6	1	0.55	1	0.52	1	1.61	1
Actual lot (j)	unit	2	1	1	1	2	1	1	1	1	1	2	1
Purchasing quantity (p)	unit	4	2	2	2	2	1	1	1	1	1	1	1
Total Ordering Cost	Baht	1,000	2,000	1,000	1,000	37,500	75,000	8,000	8,000	160,000	160,000	1,040,000	2,080,000
Total Holding Cost	Baht	312	0	0	0	29,260	0	0	0	0	0	798,063	0
Total Cost (Inventory Cost)	Baht	1,312	2,000	1,000	1,000	66,760	75,000	8,000	8,000	160,000	160,000	1,838,063	2,080,000

Table 4.10 Spare parts classification (for slow moving items)

Component	Separation Line (C^*)	Spare part unit cost (C)	Type of part		Component is fitted to	
			Low cost	High cost	EOQ	LFL
PLC Battery (for Sorter CPU)	1,444	450	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
PLC Battery for QCPU Gateway	667	695	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Inverter (4kW/480V)	55,556	21,674	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Memory card 5V flash 2 MB/16 bit	4,444	14,772	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
417-4H CPU (1.4 Mbyte)	118,518.5	432,722.5	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Control 2000 CPU (Vert. carousel)	562,963.0	216,000.0	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

Regarding Table 4.10, all spare parts shown in this table are slow-moving items. The separation line is the boundary between high and low-cost spare parts. For this study, the PLC battery (for Sorter CPU), Inverter (4 kW./480V.), and Control 2000 CPU (for vertical carousel) can be implied as low-cost parts that are suitably applied to the extension EOQ model for controlling its inventory. Otherwise, the PLC Battery for QCPU gateway, Memory card 5V flash 2MB/16 bit, and 417-4H CPU (1.4Mbyte) can be implied as a high-cost part which is suitably applied to the LFL model for controlling its inventory.

In cases used in calculating results with the Extension of EOQ model, when ordering spare parts for replacement is less than or equal to 1 unit (have to order at least 1 unit), no holding costs will occur. The results of this calculation will give results equal to those calculated using the method of the LFL model (see the holding cost and total inventory cost in Table 4.9, a case of Memory card 5V flash 2MB/16 bit and 417-4H CPU (1.4Mbyte)).

The next steps in testing and proving the extension EOQ model compared to the LFL model and the General EOQ model when considering in terms of the total inventory costs and how the results from the simulation by changing in spare part unit cost will affect to the total inventory cost for all 3 models.

There are 2 example cases of the components used to do the simulation. These will be shown in the simulation graph between spare part unit cost and total inventory cost.

1. The simulation of total inventory cost for an Inverter (4kW/480V), this part represents the low-cost spare part.
2. The simulation of total inventory cost for a PLC Battery for QCPU gateway, this part represents the high-cost spare part.

The simulation of total inventory cost by changing in spare part unit cost for an Inverter (4kW/480V) is shown in Table 4.11 and Figure 4.6.

Table 4.11 Simulation of total inventory cost (Inverter (4kW/480V)) and the comparison between the Extension EOQ model and LFL model.

Spare part unit cost (C)	Extension EOQ model	LFL model	General EOQ model
0	0.0	75,000.0	0.0
5,000	38,250.0	75,000.0	45,000.0
10,000	50,139.6	75,000.0	63,639.6
15,000	57,692.3	75,000.0	77,942.3
20,000	63,000.0	75,000.0	90,000.0
25,000	66,873.1	75,000.0	100,623.1
30,000	69,727.0	75,000.0	110,227.0
35,000	71,808.8	75,000.0	119,058.8
40,000	73,279.2	75,000.0	127,279.2
45,000	74,250.0	75,000.0	135,000.0
50,000	74,802.5	75,000.0	142,302.5
55,000	74,998.1	75,000.0	149,248.1
Break-even point (C*)	55,555.55	75,000.0	150,000.0
60,000	74,884.6	75,000.0	155,884.6
65,000	74,499.8	75,000.0	162,249.8
70,000	73,874.6	75,000.0	168,374.6
75,000	73,034.3	75,000.0	174,284.3
80,000	72,000.0	75,000.0	180,000.0
85,000	70,789.8	75,000.0	185,539.8
90,000	69,418.8	75,000.0	190,918.8
95,000	67,900.5	75,000.0	196,150.5
100,000	66,246.1	75,000.0	201,246.1

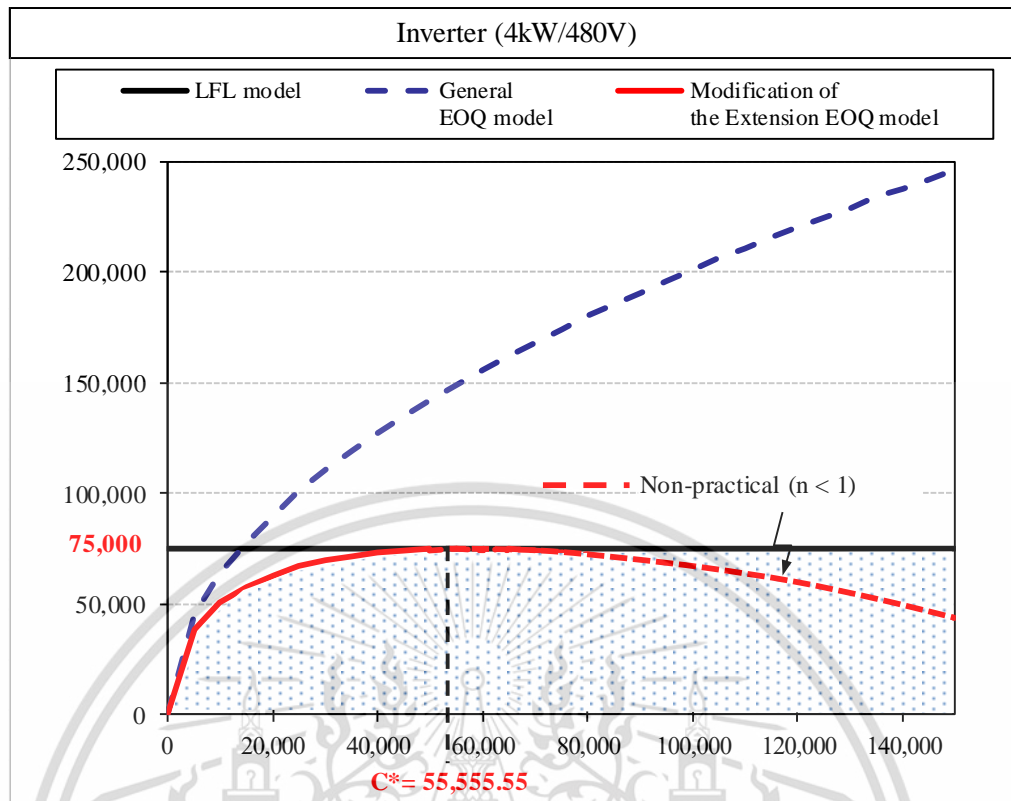


Figure 4.6 Plotting (simulation) of Total inventory cost (for Inverter (4kW/480V) equipment) against spare part unit cost (C).

Table 4.11 is the simulation of total inventory cost (for Inverter (4kW/480V)), and the break-even point (C^*) is the separation line between high-cost and low-cost materials. The break-even point is 55,555.56 Baht, the Inverter (4kW/480V) can be implied as a low-cost spare part. Figure 26 is the plotting of total inventory cost against spare part unit cost. The plotting is to confirm that the extension EOQ model is lower cost than the general EOQ model at all positions. For the point that spare part unit cost is over 55,555.56 Baht, the zone from this point forward is not practicable thinking. Because the holding cost will be the minus value which is not practical (the other spare parts have similar results). Meaningfully, spare parts are ordered in less than one lot. In practice, spare parts are always contemporary and replaced by m units (or one lot) for every change. Thus, spare parts have to be purchased by multiplication times of m units (or j lots).

Another example case is the PLC Battery for QCPU Gateway, it is the simulation of total inventory cost by changing in spare part unit cost and to be shown the results in Table 4.12 and Figure 4.7.

Table 4.12 Simulation of total inventory cost (PLC Battery for QCPU Gateway) and the comparison between the Extension EOQ model and LFL model.

Spare part unit cost	Extension EOQ model	LFL model	General EOQ model
0	0.0	1,000.0	0.0
100	624.6	1,000.0	774.6
200	795.4	1,000.0	1,095.4
300	891.6	1,000.0	1,341.6
400	949.2	1,000.0	1,549.2
500	982.1	1,000.0	1,732.1
600	997.4	1,000.0	1,897.4
666.67	1,000.0	10,000.0	2,000.0
700	999.4	1,000.0	2,049.4

Spare part unit cost	Extension EOQ model	LFL model	General EOQ model
800	990.9	1,000.0	2,190.9
900	973.8	1,000.0	2,323.8
1,000	949.5	1,000.0	2,449.5
1,100	919.0	1,000.0	2,569.0
1,200	883.3	1,000.0	2,683.3
1,300	842.8	1,000.0	2,792.8
1,400	798.3	1,000.0	2,898.3
1,500	750.0	1,000.0	3,000.0
1,600	698.4	1,000.0	3,098.4

Break-even point (C*)

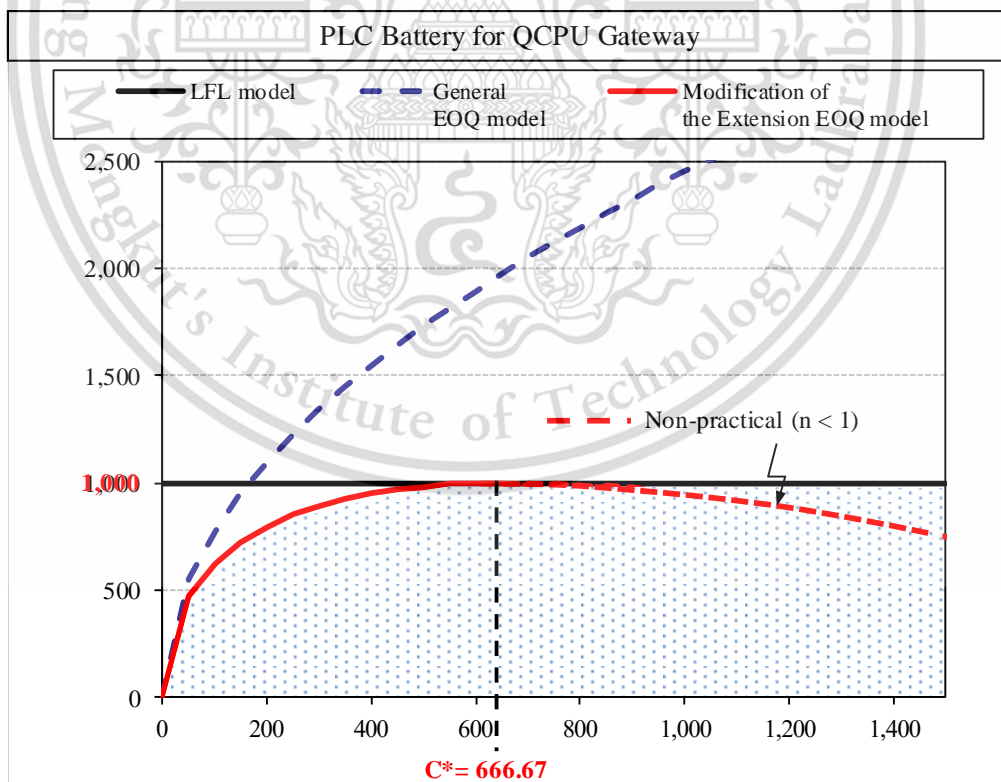


Figure 4.7 Plotting (simulation) of Total inventory cost (for PLC Battery for QCPU Gateway equipment) against spare part unit cost (C).

Table 4.12 is the simulation of total inventory cost (for PLC Battery for QCPU Gateway), and the break-even point (C^*) is the separation line between high-cost and low-cost materials. The break-even point is 666.67 Baht, and the Inverter (PLC Battery for QCPU Gateway) can be implied as a high-cost spare part. Figure 4.3 is the graph plotting the total inventory cost against spare part unit cost. The graph is to confirm that the extension EOQ model is lower cost than the general EOQ model at all positions. The point that spare part unit cost is over 666.67 Baht, this is a non-practical area. The reason for thinking is as same as the case of the Inverter (4kW/480V), and the shape of a graph and its trend and pattern are the same characteristics.

Regarding Figure 4.6 and 4.7, if n is equal to one lot then there is no holding cost. Because of new parts will be replaced all. In this case, this seems to be purchased by using the LFL model. When n is equal to one, the term of holding cost will be waived. There is only an ordering cost which is equal to the multiplication between the ordering cost per one time (S) and identical equipment (k) installed in a system. Or, it is equal to $S \cdot k$ which conforms to the LFL model. So, if a case of n is less than one, a roundup of n (or at least one lot) will be done. For this case, the LFL model will be exploited.

Case study 4: The proving of the Extension EOQ model

This is the proof for confirming the existence of the extension EOQ model. At the same time, Figures 4.9, 4.10, and 4.11 are the plotting graph of the comparison between the extension EOQ model and the general EOQ model which is used to illustrate that the extension EOQ model has a lower total inventory cost than the general EOQ model. There are three component types which are case studies as:

1. Auxiliary contact is a supplementary device being additionally installed to a breaker, used for sending remote information on the circuit breaker status, and can be used for indicating electrical locking. It is a common point changeover type contact, with a normally open (NO) and a normally closed (NC) contact.
2. Shunt trip is a supplementary device being additionally installed to a breaker for remotely controlling the disconnection of the breaker. It is a remote control without walking to disconnect the circuit breaker. It works when the coil shunt trip receives excitation voltage from another system.
3. A molded case circuit breaker (MCCB) is a type of electrical safety device used to protect the electrical circuit from excessive current, which can occur from

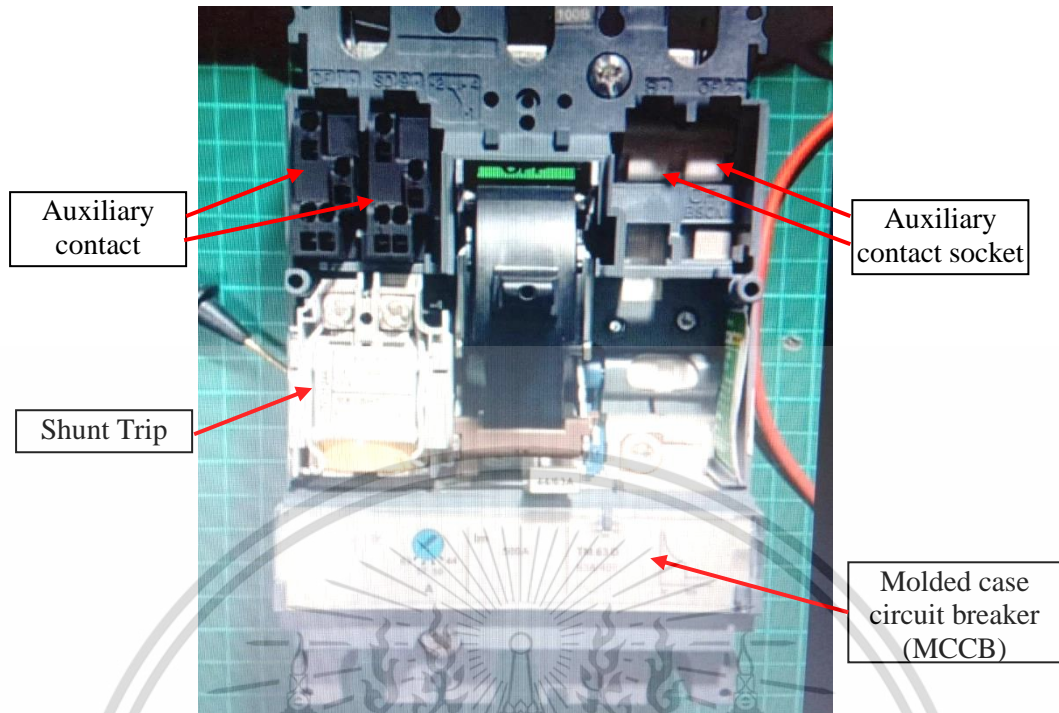


Figure 4.8 Molded case circuit breaker (MCCB) and its supplementary equipment

Table 4.13 Components details and Variables

Variable	Unit	Component		
		Auxiliary contact	Shunt trip	Molded case circuit breaker
Unit price (C)	Baht	930	3,025	21,000
Amount of identical parts in the system (k)	units	4	4	4
Lead time (L)	days	15	15	30
The usage per one changing (m)	units	2	1	1
Mean time between failure (M_{TBF})	years	10	10	20
Purchasing cost per order (S)	Baht	2,000	2,000	10,000
Fraction of Holding Cost (I)	% of unit cost	5%	10%	15%

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Component 1: Auxiliary contact

Table 4.14 Simulation (for Auxiliary contact device) of total inventory cost and the comparison between the General EOQ model and Extension EOQ model

Optimal lot size (n)	Ordering Cost	Holding Cost (General EOQ)	Total Cost (General EOQ)	Holding Cost (Extension EOQ)	Total Cost (Extension EOQ)
0		0		-465	
1	8,000	465	8,465	0	8,000
2	4,000	930	4,930	465	4,465
3	2,667	1,395	4,062	930	3,597
4	2,000	1,860	3,860	1,395	3,395
Optimal lot size (j)					
Optimal lot size (n)	4.148	1,929	3,857	1,464	3,392
5	1,600	2,325	3,925	1,860	3,460
6	1,333	2,790	4,123	2,325	3,658
7	1,143	3,255	4,398	2,790	3,933
8	1,000	3,720	4,720	3,255	4,255

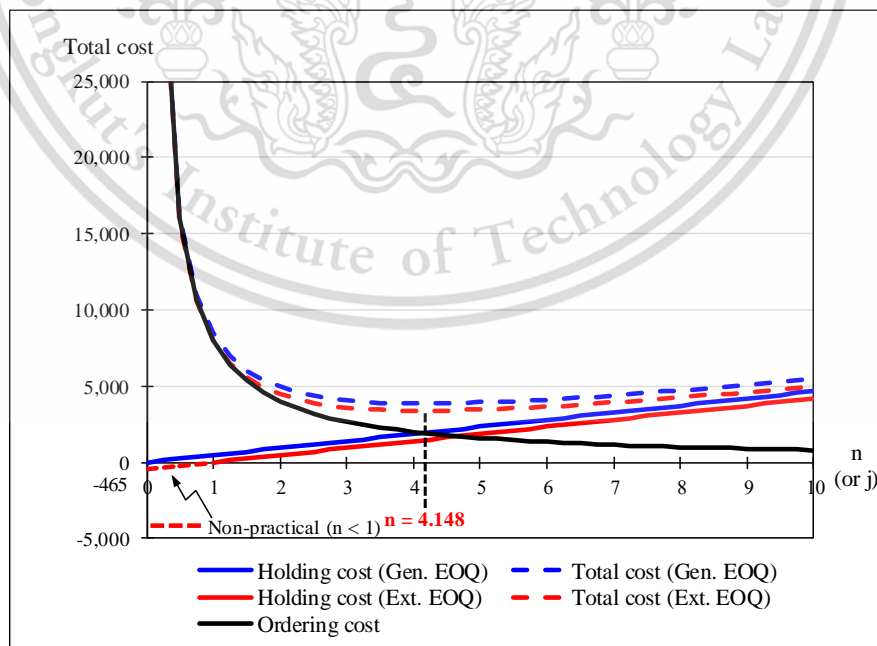


Figure 4.9 Plotting of Total inventory cost (for Auxiliary contact equipment) against the purchasing lot size (n , or Q^*).

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Component 2: Shunt trip

Table 4.15 Simulation (for shunt trip device) of the total inventory cost and the comparison between the General EOQ model and Extension EOQ model

	Optimal lot size (n)	Ordering Cost	Holding Cost (General EOQ)	Total Cost (General EOQ)	Holding Cost (Extension EOQ)	Total Cost (Extension EOQ)
	0		0		-1,513	
	1	8,000	1,513	9,513	0	8,000
Purchasing lot size (j)	2	4,000	3,025	7,025	1,513	5,513
Optimal lot size (n)	2.300	3,478	3,479	6,957	1,966	5,445
	3	2,667	4,538	7,204	3,025	5,692
	4	2,000	6,050	8,050	4,538	6,538
	5	1,600	7,563	9,163	6,050	7,650
	6	1,333	9,075	10,408	7,563	8,896
	7	1,143	10,588	11,730	9,075	10,218
	8	1,000	12,100	13,100	10,588	11,588

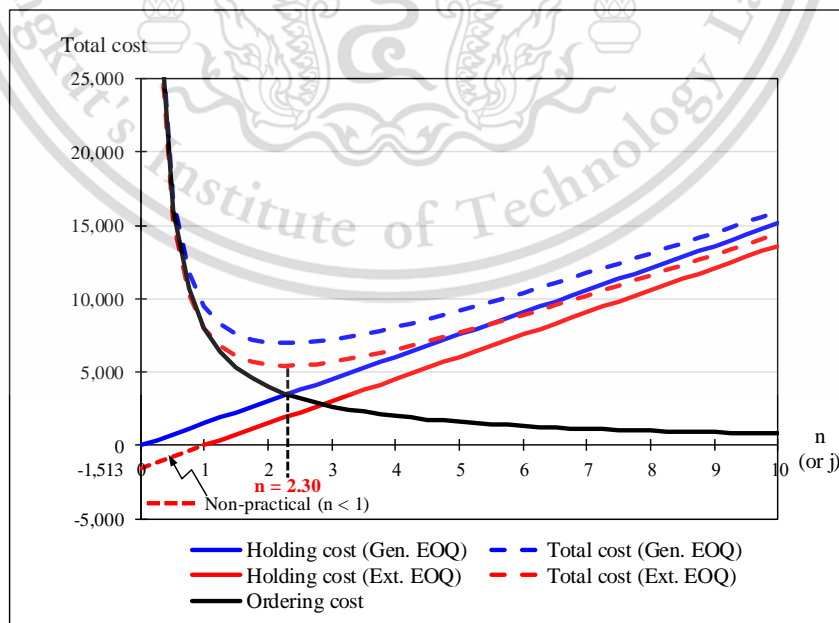


Figure 4.10 Plotting of Total inventory cost (for shunt trip equipment) against the purchasing lot size (n , or Q^*).

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Component 3: Molded case circuit breaker (MCCB)

Table 4.16 Simulation (for MCCB equipment) of the total inventory cost and the comparison between the General EOQ model and Extension EOQ model

	Optimal lot size (n)	Ordering Cost	Holding Cost (General EOQ)	Total Cost (General EOQ)	Holding Cost (Extension EOQ)	Total Cost (Extension EOQ)
	0		0		-31,500	
	1	80,000	31,500	111,500	0	80,000
Optimal lot size (n)	1.594	50,188	50,211	100,399	18,711	68,899
Purchasing lot size (j)	2	40,000	63,000	103,000	31,500	71,500
	3	26,667	94,500	121,167	63,000	89,667
	4	20,000	126,000	146,000	94,500	114,500
	5	16,000	157,500	173,500	126,000	142,000
	6	13,333	189,000	202,333	157,500	170,833
	7	11,429	220,500	231,929	189,000	200,429
	8	10,000	252,000	262,000	220,500	230,500

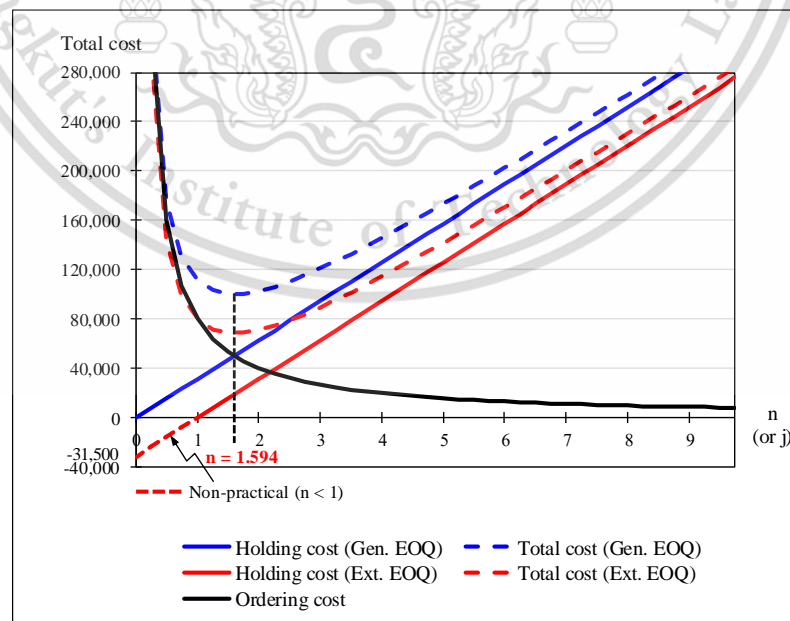


Figure 4.11 Plotting of Total inventory cost (for MCCB equipment) against the purchasing lot size (n , or Q^*).

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Regarding Table 4.14, the optimal lot size (or the cheapest purchasing) of the first case (n) is 4.148 sets. Indeed, the optimal lot size (n) is always in decimal point number, there is less chance that the optimal lot size (n) is the integer number. Therefore, the comparison between either round-up or round-down for deciding on the actual purchasing lot size should be considered according to comparing the total inventory cost to which one is the cheapest. In this case, the actual lot size (j) shall be 4 lots but the amount of purchasing is equal to $j*m$ sets (where m is the number of parts simultaneously changing at the same time). Or, it is 8 sets.

Figure 4.9 is a simulated graph plotting the relationship between total inventory costs and the number of lots ordered. This graph confirms that the number of lots specified in the previous paragraph is the size that provides the lowest total costs. For Tables 4.15 and 4.16, it is to confirm that when ordering spare parts in lots equal to 2 sets (in the case of shunt trip equipment and MCCB equipment). It will result in the lowest costs of spare parts inventory as well. This is reconfirmed by Figures 4.10 and 4.11 which show the simulation results when the order lot is equal to 2 sets, with the trend and graph characteristics being almost similar.

In summary, it can be seen that the model developed in this study is designed to fill gaps and close issues that are expected to be problems or points of ambiguity. In addition to this principle, it has been proven numerically and mathematically. This model can also be used to support the segmentation model discussed in the previous chapter. In addition, the segmentation and inventory models, when put into practice, will result in lower inventory costs than inventory using the model devised by previous research. Case studies No. 2, 3, and 4 have been tested and proven to actually save on spare parts inventory costs according to the mathematical numbers presented earlier.

The next case study (Case Study 5) will be a classification of spare parts by separating the form and type of use. From what was mentioned in Chapter 2 previously, it can be divided into eight groups or eight baskets based on the 3 main factors. This is the summary and final part of testing and proving this research.

Case Study 5: Classifying of spare parts (MRO) for 8 baskets inventory system

This is the final classification for all spare parts (MRO) types, it will be grouped as individual baskets. Each basket (group) is managed and controlled by the appropriate inventory models which are addressed in Chapter 2. Particularly, each model is thought based on the characteristics and aspects of classifying each spare parts group.

Table 4.17 Classifying for all spare parts to be filled in each individual basket

No	Component	Factor	Movement		Necessity		Cost		Basket No.
			Fast	Slow	Much	Less	High	Low	
Mechanical Component									
1	Smooth top belt (unit in meter)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
2	Rough top belt (unit in meter)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
3	Flat belt 30 Degree KT96A		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
4	Flat belt 45 Degree KT96A		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
5	Flat belt 60 Degree KT96A		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
6	Flat belt 90 Degree KT96A		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
7	Spiral belt 45 KT96A (Ht:300 mm)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
8	Spiral belt 90 KT96A (Ht:300 mm)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
9	Spiral belt 90 KT96A (Ht:600 mm)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
10	Merge belt KT263		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
11	Divert belt KT263		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
12	Bearing (Drive pulley) Ø 55 mm.		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
13	Bearing (Head/Tail pulley) Ø 35 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
14	Take-up Bearing Ø 35 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
15	Bearing non housing Ø 30 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
16	Bearing non housing Ø 35 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
17	Bearing non housing Ø 45 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
18	Bearing non housing Ø 55 mm.		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
19	Drive pulley - Ø 185, 35 (SA57)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
20	Drive pulley Ø 235, 45 (SA67)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
21	Drive pulley - Ø 235, 55 (SA77)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
22	End pulley - Ø 140, 35 (Head-Tail)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
23	Return roller - Ø 76, 25		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
24	Snub and Bend pulley - Ø 102, 30		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
25	Take-up pulley - Ø 140, 35		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
26	Drive pulley Ø 185, 40 (SA67)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
27	Drive pulley (Queue) Ø 185, 35 (SA57)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
28	Flat drive pulley Inside 30mm (KA37)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
29	Flat drive pulley inside 30mm (SA47)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
30	Flat drive pulley outside 30mm (KA37)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
31	Flat drive pulley outside 30mm (SA47)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
32	Flat tail pulley		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
33	Flange with bearing Ø 25 mm.		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
34	Flange with bearing Ø 35 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
35	Trommellager 25mm with bearing		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2

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Table 4.17 The classifying for all parts to be filled in each individual basket (Cont.)

No	Component	Factor	Movement		Necessity		Cost		Basket No.
			Fast	Slow	Much	Less	High	Low	
31	Flat drive pulley outside 30mm (SA47)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
32	Flat tail pulley		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
33	Flange with bearing Ø 25 mm.		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
34	Flange with bearing Ø 35 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
35	Trommellager 25mm with bearing		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
36	Trommellager 35mm with bearing		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
37	Bearing non housing Ø 25 mm.(power turn)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
38	Bearing for holder (Power turn)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
39	Upper quick release holder c/w bearing		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
40	Lower quick release holder c/w bearing		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
41	Spiral drive pulley inside 30mm (SA47)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
42	Spiral drive pulley inside 30mm (SA57)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
43	Spiral drive pulley outside 30mm (SA47)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
44	Spiral drive pulley outside 30mm (SA57)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
45	Spiral tail pulley		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
46	Y-Bearing take-up unit SKF-TU35TF		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
47	Guidance roller		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
48	Precision roller Ø 65 ,NW=1000 mm		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
49	Self Aligning with Spring Ball is the D-nut		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
50	Back up roller Ø 65, N=1000 mm		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
51	Flange with bearing Ø 40 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
52	Grooved ball bearing		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
53	Bearing for precision roller		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
54	Roller castor Ø 50		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
55	Belt tracking station		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
56	Friction bearing (Poly mer bushing)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
57	Swing plate		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
58	Brass bushing		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
59	Distance tube		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
60	Shaft for 45 degree merge		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
61	Deck Board for Merge Conv.		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
62	Hexagon head screw, M 8x200 (Galvanised)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
63	Belt guiding stud		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
64	Pressure spring (long type)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
65	Tracking station pressure spring (Short)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
66	Upper nose bar coated 45 Degree		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
67	Lower nose bar coated 45 Degree		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
68	Activation unit, left		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
69	Activation unit, right		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
70	Block gasket		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
71	Bottom part, relief, back		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
72	Code plate		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
73	Con-kit, front, W1000		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
74	Con-kit, rear, W1000		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
75	Cover bottom curve 15deg R3000		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8

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Table 4.17 The classifying for all parts to be filled in each individual basket (Cont.)

No	Component	Factor	Movement		Necessity		Cost		Basket No.
			Fast	Slow	Much	Less	High	Low	
76	Cover for cart profile 1250		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
77	Diverting brush		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
78	Spring 1160 for Tilt tray sorter		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
79	Suspension f.cover back level		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
80	T bolt 28/15 special M10*25		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
81	Tilting device, S2000		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
82	Tray width=1000, Pitch 1250v		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
83	Wire loop cart		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
84	Eccentric ball-and-socket joint		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
85	Support front rear kit		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
86	Retrofit kit wheel		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
87	Wheel d90, Blickle 02		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
88	Threaded bushing M8x012x15 (St)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
89	Skive D=28 d=8.5 H=4.5		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
90	Screw UH Ub 8.8 FZB M8x20		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
91	Tight - Fitting bolt complete		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
92	Tooth plate		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
93	Activation arm		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
94	Locking plate		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
95	Machaine screw pan head		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
96	Lock nut with nylon washer		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
97	Stop plate of collision device		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
98	Adjustment nut		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
99	Adjustment screw (short)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
100	Transition Belt,L=2147 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
101	Transition Belt,L=2319 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
102	Transition Belt,L=2491 mm.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
103	Belt Induction BW1000 L26 (2634)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
104	Belt Induction BW1000 L37 (3729)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
105	Belt Induction BW1000 L39 (3929)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
106	Belt guide		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
107	Drive Roller CPL D90W1000-50		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
108	Drive Roller CPL 80/100 HD G2		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
109	Wheel Complete		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
110	Roller for Induction conv.		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
111	Tooth belt 900		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
112	Tooth pulley		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
113	Rod end bearing for conv. SCF 20ES		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
114	Rod end bearing for conv. SCF 25ES		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
115	Rod end bearing for conv. SAKAC 20M		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
116	Rod end bearing for conv. SAKAC 25M		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
117	End bearing for VSC		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
118	Drive bearing for VSC		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
119	Pressing unit for carousel		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
120	Stainless steel slat		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8

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Table 4.17 The classifying for all parts to be filled in each individual basket (Cont.)

No	Component	Factor	Movement		Necessity		Cost		Basket No.
			Fast	Slow	Much	Less	High	Low	
121	Tension Unit		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
122	Load Wheel		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
123	Chain Link		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
124	Friction belt for drive		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
125	Plastic Bumper with Guide Pin		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
126	Chain Link Pin		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
127	Chain Link Pin (Alignment)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
128	Oil Seal AS 45x75x8-NBR (KA37/SA47)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
129	Oil Seal BASF65x100x12-NBR (SA67-Ou		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
130	Oil Seal B1SF65x94x10/14.5-FKM(SA67-		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
Electrical component									
131	Passenger display		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
132	Connecting cable 1.5m		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
133	Power adapter (IND205 UK)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
134	Half-wave rectifiers 400VAC, 3A		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
135	Sensor f/ioc left		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
136	Control box key reset 24 VDC		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
137	Grounding wire for cart		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
138	Repeater for profibus		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
139	FQ+M 3.0/1.5kW (Drive unit for motor)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
140	PLC battery (for Sorter)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
141	PLC/Battery for QCPU		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
142	PLC battery (for Sorter memory)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
143	PLC/Battery for QCPU Gateway		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
144	PLC/Redundant CPU Module (QCPU)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
145	PLC/Redundant Power Supply Module		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
146	417-4H CPU (1.4 Mbyte)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
147	Memory card 5V flash 2 MB/16 bit		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
148	PLC Power supply module		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
149	Sync. Modules for H-system		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
150	BUS Cables		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
151	Profibus bus connection		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
152	Electr.blok ET200S 2XAO		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
153	Electronic Module for ET200S 4DI		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
154	Electronic Module for ET200S 4DO		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
155	Interface module IM 151-1 for ET200S		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
156	Power Module for ET200S		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
157	Power supply 24 VDC 10A 100/240V (So		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
158	4P Plug - in Relay (24VDC)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
159	Terminal Modules for Power (ET200S)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
160	Terminal Modules for Electronic (ET200S)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
161	Control 2000 CPU (Vert. carousel)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
162	Voltage regulator		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
163	Machine Control MIF 2		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
164	Operator control panel (Vert. Car)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	1
165	Light Barrier Transmitter		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2

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Table 4.17 The classifying for all parts to be filled in each individual basket (Cont.)

No	Component	Factor	Movement		Necessity		Cost		Basket No.
			Fast	Slow	Much	Less	High	Low	
166	Current circuit-breaker		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
167	Proximity Switch		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
168	Limit switch		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
169	Automatic cut-out 440V AC 6A 1pole C		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
170	Fluorescent Lamp 35 W		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
171	Photoelectric proximity sensor (MU)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
172	Fuse sensor (Fuse metal)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
173	Thermal protector 125C (FSD)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
174	Omron Relay G2R-1-SND DC24V		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
175	2P Omron Relay (12VDC 10A)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
176	2P Omron Relay (24VDC 10A)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
177	Fan fot ATR		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
178	Optical-Encoder		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
179	Lamp glass LED (Pilot lamp)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
180	SC5000-1000 (Controller)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
181	DS8110-2100 (Laser Scanner)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	1
182	Vent. Fan (throughput 230m3/h,AC230V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
183	Vent. Fan (throughput 500m3/h,AC230V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
184	UPS (230V, 1500VA / 865W)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
185	External Battery Pack for UPS		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
186	Soft starter (SMC-3 150-C19 NBR)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
187	Soft starter (SMC-3 150-C3 NBD)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
188	Soft starter (SMC-3 150-C9 NBD)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
189	Direct adaptor link		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
190	Magnetic Contactor (24VDC Coil)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
191	Magnetic Contactor (1NO,1NC Coil:DC24V)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
192	Connection Block		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
193	Motor Breaker (3P 1.6-2.5A 100kA/400VAC)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
194	Motor Breaker (3P 2.5-4A 100kA/400VAC)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
195	Motor Breaker (3P 4.0-6.3A 100kA/400VAC)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
196	Motor Breaker (3P 6-10A 100kA/415VAC)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
197	Motor Breaker (3P 0.63-1A 50kA/400VAC)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
198	Motor Breaker (3P 1-1.6A 50kA/400V)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
199	Motor Breaker (3P 6.3-10A 50kA/400V)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
200	Motor Breaker (3P 1.6-2.5A 50kA/400V)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
201	Motor Breaker (3P 2.5-4A 50kA/400V)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
202	Motor Breaker Aux Switches (1 NO+1 NC)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
203	Inverter FC280(5.5KW/3x380-480VAC)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
204	Inverter ACS355 Drives (0.75 KW.)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
205	Inverter (4kW/480V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
206	Power supply (4.5A,24VDC)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
207	Power supply (14A,24VDC)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
208	Power supply (27A,24VDC)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
209	Power Supply (50A,24VDC)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
210	Power supply (70W AC220/DC24V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6

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No	Component	Factor	Movement		Necessity		Cost		Basket No.
			Fast	Slow	Much	Less	High	Low	
211	Power supply (100W AC220/DC15V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
212	Power supply (150W AC220/DC24V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
213	Power supply (220W AC220/DC24V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
214	Power supply (350W AC220/DC24V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
215	CC-Link Remote Input 16 points(7mA)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
216	CC-Link Remote Input 32 points (7mA)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
217	CC-Link Remote Input 32 points (5mA)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
218	CC-Link Remote Output 16 points (7mA)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
219	CC-Link Remote Output 32 points (7mA)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
220	CC-Link Remote Output 32 points (5mA)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
221	Key selector switch, 3-Stay put		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
222	2P Plug - in Relay (230VAC)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
223	3P Control Relay /AC230V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
224	4P Omron Relay (110 / 120 VAC 5A)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
225	Earth Leakage Relay (AC 110/240V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
226	Warning Alarm (TypeA)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
227	Warning Alarm (TypeB)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
228	FUSE LINK 80A		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
229	FUSE LINK 160A		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
230	FUSE BASE 160 A (ABB)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
231	Tranciever Sensor		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
232	Switch disconnect (Type A)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
233	Switch disconnect (Type B)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
234	Computer Controller for VMC800		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
235	Illuminated emergency switching head		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	4
236	Emergency stop switches		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
237	Contact block for emergency switch		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
238	Brake Control (Rectifier)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
239	MCCB (3P 250AF 250AT 35kA/480V)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
240	Shunt trip 380-415V, 50/60Hz		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
241	Auxiliary contact 1No/1NC		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
Electro-Mechanical component									
242	Drum Motor (Weighted Conveyor)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
243	Weight scale		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
244	Gear motor 0.75 kW (i=7.28)		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
245	Gear motor 0.75 kW (i=8.64)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
246	Gear motor 0.75 kW (i=9.23)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
247	Gear motor 0.75 kW (i=10.80)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
248	Gear motor 0.75 kW (i=12.10)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
249	Gear motor 0.75 kW (i=14.24)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
250	Gear motor 0.75 kW (i=16.47)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
251	Gear motor 0.75 kW (i=17.62)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
252	Gear motor 0.75 kW(i=20.33)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
253	Gear motor 1.1 kW (i=7.28)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
254	Gear motor 1.1 kW (i=9.23)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
255	Gear motor 1.1 kW (i=14.24)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5

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Table 4.17 The classifying for all parts to be filled in each individual basket (Cont.)

No	Component	Factor	Movement		Necessity		Cost		Basket No.
			Fast	Slow	Much	Less	High	Low	
256	Gear motor 1.5 kW (i=10.03)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
257	Gear motor 1.5 kW (i=12.96)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
258	Gear motor 1.5 kW(i=13.73)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
259	Gear motor 2.2 kW (i=8.69)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
260	Gear motor 2.2 kW(i=10.03)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
261	Gear motor 2.2 kW. (i=11.03)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
262	Gear motor 2.2 kW (i=15.60)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
263	Gear motor 2.2 kW (i=20.37)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
264	Gear motor 2.2 kW (i=23.33)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
265	Gear motor 3 kW (i=9.44)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
266	Gear motor 3 kW (i=12.07)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
267	Gear motor 3 kW (i=13.76)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
268	Gear motor 3 kW (i=15.28)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
269	Gear motor 3 kW (i=18.42)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
270	Gear motor 3 kW (i=20.99)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
271	Gear motor 3 kW (i=32.38)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
272	Gear motor 4 kW (i=15.28)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
273	Gear motor 4 kW(i=18.42)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
274	Gear motor 4 kW (i=20.99)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
275	Gear motor 4 kW (i=25.07)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
276	Gear motor 4 kW (i=28.41)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
277	Gear motor 4 kW (i=32.38)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
278	Multisuspension linearmotor		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
279	Linearmotor with Heat sink		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
280	FQ Motor 3.0/1.5kW		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2
281	Gear motor 0.75kW (i=6.80)(RHS) - VSC		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
282	Gear motor 0.75 kW(i=6.80)(LHS) - VSC		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	5
283	Gear motor drive arm 1.5 kW(i=22.66)		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6
284	Disc Brake Complete BMG1 Vb 230VAC		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	7
285	Disc Brake Complete BMG1 Vb 400VAC		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	6

Table 4.18 Summary of spare parts (Components) types in each basket

Basket No.	1	2	3	4	5	6	7	8
Type of Spare parts	FMH	FML	FLH	FLL	SMH	SML	SLH	SLL
Amount	2	126	0	1	39	102	1	14
Percent (%)	0.70%	44.21%	0.00%	0.35%	13.68%	35.79%	0.35%	4.91%

Basket 2 is the most fitting to the observations data (126 component types, 44.21%) and the second fitting basket is basket 6 (102 component types, 35.79%). A similar element between basket 2 and basket 6 is the exploiting of the EOQ model, because of EOQ model is usually used for inventory control in the form of these spare parts.

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Basket 3 has no observation data fitting inside because basket 3 is the paradox of spare parts usage by reasons of which the constituents inside this basket are composed of fast movement, less necessity, and high cost. In practice, it is impossible that a high-cost spare part will either be less necessary or a high-cost spare part should probably be less consumed (slow movement). Therefore, basket 3 will not have any observation data inside at all.

If such a case occurs, then it indicates that the system has a problem, and the maintenance manager may have to analyze the cause and find a solution to prevent it.

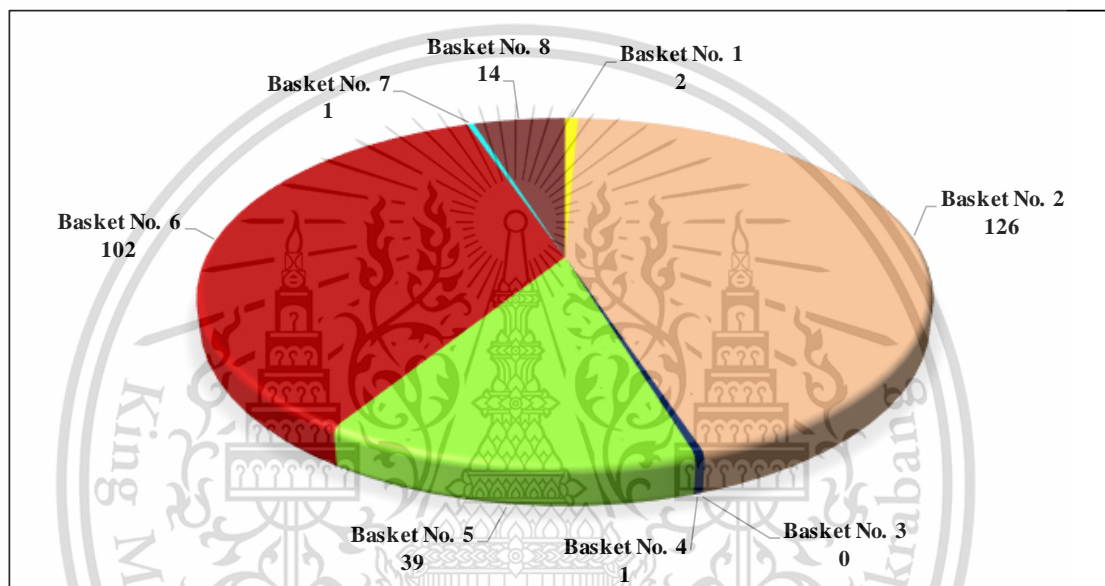


Figure 4.12 Pie chart (in the amount of spare part type) of observation data in each basket after classifying.

For the other baskets (see Figure 4.12 and Table 4.18), it is normally a situation that will occur corresponding to its occasions that are dependent on the conditions and characteristics of spare parts consumption. However, all baskets are still important, if some baskets are omitted then all parts cannot be entirely managed, and it may produce more inventory cost.

The table below (Table 4.19) summarizes the proven method of using the spare parts inventory for each basket, broken down by the type of spare parts used. Previously, it was said that it was more economical, easier, and reliable than the previous one.

Table 4.19 Conclusion of Eight Baskets Inventory System

Basket	Characteristics of Demand (Movement-Necessity-Cost)	Re-Order Point	Purchasing Quantity	Safety Stock
1	Fast-Much-High	Failure occurrence	m units	SS with Normal Distribution
2	Fast-Much-Low	Lead Time	Q^*	SS with Normal Distribution
3	Fast-Less-High	Failure occurrence	m units	None
4	Fast-Less-Low	Lead Time	Q^*	None
5	Slow-Much-High	Failure occurrence	m units	SS with Poisson Distribution
6	Slow-Much-Low	Lead Time	p	SS with Poisson Distribution
7	Slow-Less-High	Failure occurrence	m units	None
8	Slow-Less-Low	Lead Time	p	None

Conclusively, the summary of the eight-basket inventory system is shown in Table 4.19. Spare parts can be classified into eight baskets (or groups). And all individual groups will be taken into appropriate account with the suitable model to be proposed for finding the optimal inventory policy.

CHAPTER 5

CONCLUSION AND DISCUSSION

Generally, it is believed that spare parts management and inventory control are not interested in finding optimal solutions. The factory managers or maintenance managers did not focus on new methods and models for supporting their inventory control policy. And the reasons often given include:

1. The EOQ model is the most popular model that can always be exploited with the optimal solution available, and it has provided satisfactory solutions in the past.
2. The LFL model is also exploited by small factories, which utilize a small number of spare parts. This is the simplest method to be used for the arrangement of spare parts inventory control, but it does not perform in some dependent criteria. And it has some problems with the huge ordering costs whenever equipment failures frequently occur.
3. Some special algorithms, like the Wagner-Whitin algorithm, always guarantee an optimal solution, but they are difficult to use, and this can only fix patterns of spare parts demand in the past without any flexibility in equipment failure variation, which is the real-world situation. In addition, the abundance of spare parts types will complicate the inventory control policy, and if you spend a lot of time finding the optimal inventory, it may not be suitably applied to this algorithm.
4. The other model, like Period Order Quantity (POQ), just corresponds to the ordering period, but it is not better than the EOQ model in terms of lower cost. Furthermore, there are dynamic lot sizing models such as the Part Period Balancing model (PPB), Least Unit Cost model (LUC), and Least Period Cost model (LPC). These models do not have the same flexibility in failure variation as the Wagner-Whitin algorithm, so they may not be suitable to be applied to spare parts demand.
5. Managers may not know or be aware of the new concepts and models providing for better solution methods.

5.1 Conclusion

In fact, settling for a satisfactory solution for the inventory model of previous studies is not enough. Thus, the findings of this study are consistent with the findings of many other previous models and inventory management policies on the optimal the optimal decision-making of spare parts. This research also found that there are limitations on:

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1. The complexity of spare parts management requires individual and group decision-makers to choose simplistic heuristic models that provide approximate solutions to problems facing them.
2. A huge number of spare part types have provided consistent evidence of direct and indirect antecedent effects of characteristics upon information utilization within the spare parts management policies. In most cases, the large number of spare parts makes inventory calculations time-consuming. It is difficult and complicated.
3. The models and their variables, as reported in the previous studies, include uncertainty and complexity. The models are not suitably applied to real-life situations. The simplicity of models should rather be provided to ensure those relevant people can easily understand them without any mistakes in using them.
4. If the inventory management decisions are highly complex and subject to uncertainty and variables. They are influenced by the aforementioned cognitively complicated models. If managers choose the simplex model rather than complex models, they may gain a time advantage in seeking approximate solutions rather than optimal solutions to their inventory control problems.
5. However, those previous approaches may not minimize the overall inventory cost and do not take the consequences of time consumption uncertainty into consideration. Over the long run, the firm might be vulnerable to losing too much money on inventory management. For example, consider the intense consumption of too many types of spare parts. In these and similar situations, managers need to improve the quality of their inventory policies. Deciding to use optimal inventory policies such as those presented here does not take much additional manager's time and can dramatically improve the firm's ability to gain a competitive advantage.

Conclusively, the aim of this study is to solve the previous problem of the difficulty of finding spare parts for inventory management. Because almost all previous studies about spare parts inventory management for complex systems are very complicated and difficult to find. And most of them are composed of difficult mathematical models or complicated arithmetic.

5.2 Discussion

From the reasons in the previous paragraph. Consequently, this study is cognitive thinking based on an easy mathematical ratio; therefore, it is suitably applied to classify spare parts inventory management for complex systems. In addition, the statement of these three ratios in this study seems to be a more reasonable consideration than the previous. Because of:

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1. This thinking about the necessity factor or criticality is based on the cause of having spare parts in storage by comparing them against the production loss cost. If it is classified as a critical part, then the part must be stocked to ensure that it will be in hand at all times. Or, critical spare parts should have a higher production loss cost (when they breakdown) than spare part holding costs. Contrary to this, if it is classified as a non-critical part, then the part can be allowed to be a shortage (or stock-out). Or, spare parts should have a lower production loss cost (when they breakdown) than spare part holding costs.
2. This thinking about high-cost and low-cost materials is based on a comparison between the well-known model, the EOQ model, and the simplest, easy model, the LFL model. These two models are the most popular inventory management approaches. The ratio occurrence after the comparison is also easy to understand and make sense of. If spare parts are implied as high-cost materials, then they should not be stocked or bought when the need arises. Otherwise, if it is implied as a low-cost material, then it should be stocked according to its periodic demand. This can reduce overall inventory costs at all. Without this comparison, the EOQ model never indicated the separation between high- and low-cost materials, so the factory may have to pay more for spare parts holding costs. Otherwise, the LFL model just mentioned only purchasing new orders when demand occurs, so it may take a risk about the waste of money in the ordering cost. The benefits of this comparison are already illustrated and shown in Appendix 2.
3. The arithmetic of this study is already entirely considered by combining all important factors such as movement, necessity, and cost. And these three contribution factors are the key concept of this study because this classification has never been studied before. Furthermore, each individual basket (group) of spare parts classification is taken into account with its appropriated model. In addition, the safety stock concept of this study also provides the best context and solution in accordance with the characteristics of spare parts in each basket. Therefore, this is the heart or contribution to knowledge of this study.

Practically, almost all factories have utilized a lot of spare parts, and there are many types of equipment. So, it may take a long time to classify all of them, but the easy ratio will be useful and beneficially help this classification to be taken in a short time and easily. Additionally, all contribution factors and their variables in this study are designed to make it very easy to collect the data compared to previous studies. If the factory has already implemented the computerized maintenance management system (CMMS), then it is easier to do this because the programmer just modifies the CMMS by entering some easy, special

formulations in the program as automatic calculations, and the result of this classification will be automatically shown without any mistakes in the calculation.

5.3 Implications and Recommendations

This research study is focused on both dependent and independent patterns of continuous and intermittent spare part demand. So, this system inventory model and theory will be useful for spare parts management, and all constituent models in the inventory system are optimized in accordance with the characteristics of each individual basket. However, the eight-basket inventory system was originally modeled and modified for a maintenance approach. This inventory system is beneficially used for the big factories or central warehouses, which have a lot of machines with high utilization of spare parts usage, such as the car service center's central warehouse, airport equipment, mass rapid transit, power plants with substations, telephone exchanges center, remote stations, and so on. Nevertheless, this inventory management policy and its models will be unfavorable to small factories or plants that have few machines or low spare parts usage. Moreover, this research study can be applied to another purpose, such as material planning for manufacturing. However, this study is focused on spare parts inventory management. It does not concern other factors such as warehouse space, maintenance budget, set-up time, and so on.

5.4 Limitation of the Study

All assumptions and constraints appearing in Chapter 1 are the limitations and constraints of this study. Then the future research will be focused on taking those assumptions out. Thus, the additional study will be issued in order to eliminate the assumptions one by one and will take them as the important variables.

For example, if the assumption about the constant failure rate has to be taken out, then the independent failure rate over time, such as a decreasing or increasing failure rate, should be considered. The varying lead time of spare parts (or lead time that is not constant) must be considered, so this will improve and construct more reliable models for this study. Therefore, the future study may consider and focus on the other factors for developing this inventory model to be entirely completed.

The most important thing is that all assumptions should not be taken out of the one case study unless there is some special thinking to reduce the complexity of the model. Because of

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the previous belief, this study is basically proposed based on thinking about the easy way to understand rather than the difficult-to-read mathematical model or complex arithmetic. And the aim of this study is firstly to propose that every model be simple and not difficult to implement.

5.5 Future research and Direction for the extension of this research

From what was said in Section 5.4, the assumptions shown in Chapter 1 are the limitations of this research. Therefore, the guideline for further research is to remove assumptions one by one so that research can be conducted to further this research. But because the thinking method must take into account 3 things: ease of use, ease of understanding, and must not be complicated. The final important thing is that it can meet the needs of large, highly complex systems that require a large number of spare parts.



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APPENDIX A

The comparison between LFL and EOQ model for fast moving items

Lot-For-Lot (LFL) Model

Lot-for-Lot ordering is the simplest approach of all. An order is scheduled for each period in which a demand occurs. Items are purchased in the exact quantities (or number of equipment breakdowns) for each period. So, no items are held over from period to period. Hence, this approach virtually eliminates the inventory holding cost because there is a zero-inventory balance at the end of each period (Tersine, 1994). Therefore, total inventory cost just has ordering cost as:

$$\text{Total inventory cost} = S \cdot k \cdot \lambda \quad (\text{A1})$$

Where: S is ordering cost

λ is component failure rate

k is number of identical components installed in the system.

Note: The equation as above does not depend on variables m , which are simultaneous parts replacements and changes at the same time.

Economic Order Quantity (EOQ) Model

The order size is considered by minimizing the total inventory cost, which is well known as the economic order quantity (EOQ). Total inventory cost is a combination of ordering (set-up cost) cost and holding cost as:

Total inventory cost = ordering cost + holding cost

$$TC_{EOQ} = S \left(\frac{mk\lambda}{Q^*} \right) + CI \left(\frac{Q^*}{2} \right) \quad (\text{A2})$$

Comparison between LFL model and EOQ model

The comparison between the LFL and EOQ models is issued in order to minimize the total inventory cost and determine which one is the cheapest. Thus, the comparison between the two approaches can be shown by the following equations:

Total inventory cost = Total inventory cost
of LFL model of EOQ model

$$Sk\lambda = S\left(\frac{mk\lambda}{Q^*}\right) + CI\left(\frac{Q^*}{2}\right)$$

By: $Q^* = \sqrt{\frac{2S(mk\lambda)}{CI}} = \sqrt{\frac{2Sm}{CI\theta}}$

Where: Q^* is economic order quantity by using EOQ model calculation.

m is identical parts which are simultaneous changed on the same time.

C is material (spare part) unit cost.

I is holding cost fraction (in percentage of part unit cost).

θ is system mean time between failures.

Thus: $Sk\lambda = (Smk\lambda) \cdot \left(\frac{1}{\sqrt{2Smk\lambda/CI}}\right) + \left(\frac{CI}{2}\right) \sqrt{\frac{2Smk\lambda}{CI}}$

$$Sk\lambda = \frac{1}{\sqrt{2}} (\sqrt{Smk\lambda})(\sqrt{CI}) + \frac{1}{\sqrt{2}} (\sqrt{Smk\lambda})(\sqrt{CI})$$

$$Sk\lambda = \frac{2}{\sqrt{2}} (\sqrt{Smk\lambda} \cdot \sqrt{CI})$$

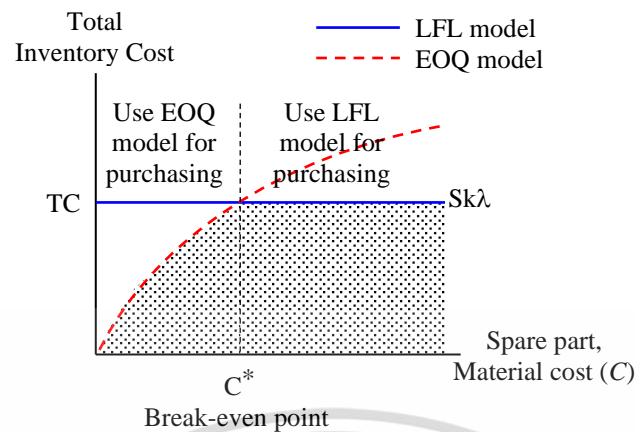
$$(Sk\lambda)^2 = 2(Smk\lambda)(CI)$$

Then: $C^* = \frac{Sk\lambda}{2mI} = \frac{S}{2mI\theta}$ (A3)

Regarding equation (A3), C^* represents the break-even point between the LFL model and the EOQ model for material (or spare parts) purchasing. Or, it is implied as the significant separation line between high- and low-cost materials. The plotting between total inventory costs and material (spare part) unit costs is:

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Appendix Figure 1 The plotting of LFL model and EOQ model

According to Appendix Figure 1, the interception and slope of the graph line for the comparison between the LFL and EOQ model can be suggested as follows:

Interception = 0 (at the origin point)

When: $C < \frac{Sk\lambda}{2mI}$; Total inventory cost = TC_{EOQ}

$$\begin{aligned} \text{Slope} &= \frac{dTC_{EOQ}}{dC} \\ &= \frac{d(\sqrt{C}\sqrt{2Smk\lambda I})}{dC} \\ &= \frac{\sqrt{2Smk\lambda I}}{2\cdot\sqrt{C}} \end{aligned}$$

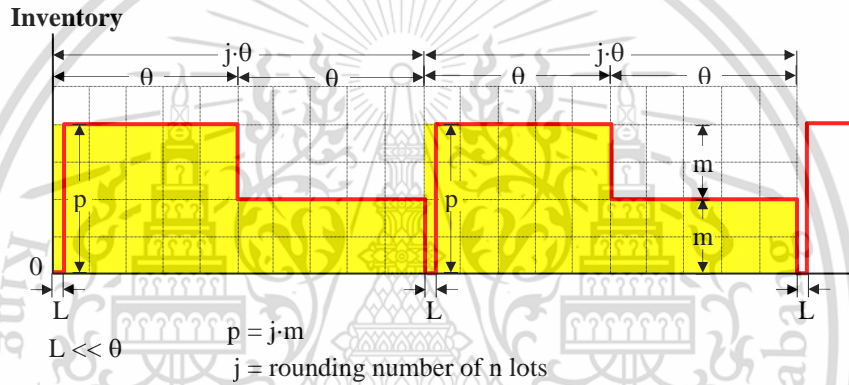
When: $C > \frac{Sk\lambda}{2mI}$; Total inventory cost = TC_{LFL}

$$\text{Slope} = \frac{dTC_{LFL}}{dC} = 0$$

Appendix B

The extension of EOQ model (EOQ model for slow moving items)

In terms of slow-moving items (or discrete demand), the general EOQ model may not perform for the reasons explained in Chapter 2. Then the extension EOQ model will be issued, corresponding to the intermittent (discrete) demand for spare parts. But the slow movement analysis is based on the parts that are probably the most used. Therefore, the optimal lot size will first be found.



Appendix Figure 2 The forming operation of extension EOQ model

Supposedly, alphabet n is defined as the optimal lot size. Then the total inventory cost of the extension EOQ model is:

$$\begin{aligned}
 TC &= S \frac{k}{n} + CI \cdot m \left(\sum_i^n i \right) \cdot \left(\frac{M_{TBF}}{n} \right) \\
 &= S \frac{k}{n} + CI \cdot m \left[\left(\frac{n}{2} \right) \cdot (n+1) \right] \cdot \left(\frac{M_{TBF}}{n} \right) \\
 &= S \frac{k}{n} + CI \cdot m \left(\frac{n+1}{2} \right) \cdot M_{TBF}
 \end{aligned}$$

DWT TC to n and set it as zero, then:

$$\frac{dTC}{dn} = -\frac{Sk}{n^2} + CI \cdot m \cdot \left(\frac{M_{TBF}}{2} \right)$$

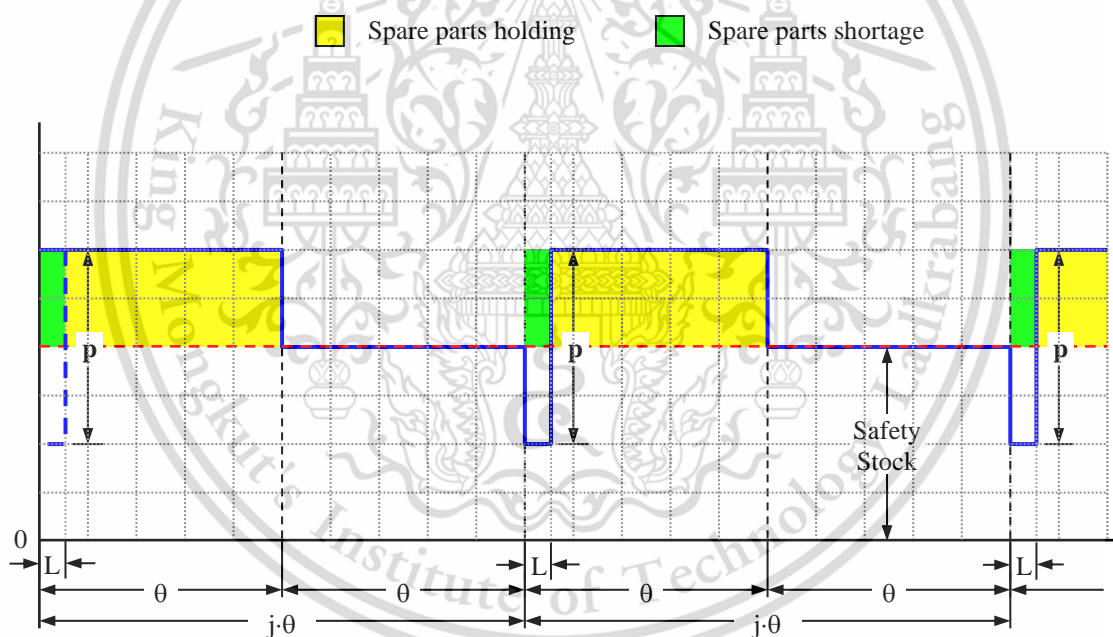
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$$n = \sqrt{\frac{2Sk}{C \text{Im} M_{TBF}}} = \sqrt{\frac{2S}{C \text{Im} \theta}} \quad (\text{B1})$$

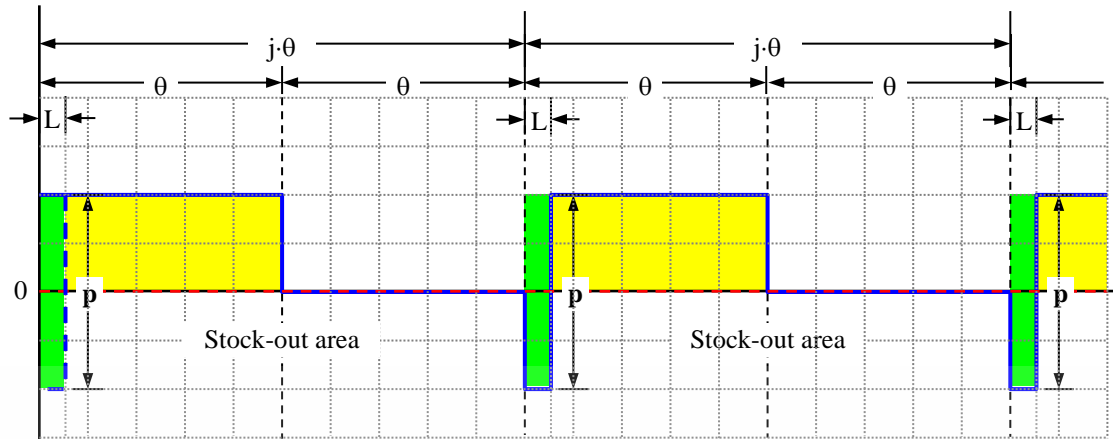
In fact, the optimal lot size (n) may not usually be an integer number and has a greater chance of being a decimal point number. So a rounding operation (round-up or round-down) for the n -lot size will be done in order to find the minimum total cost. If alphabet j is defined as a rounding number of n lot sizes, which is an integer number, and the actual purchasing quantity (p) is the multiplication between the actual lot size (j) and the components that have simultaneously changed equal to m parts.

Practically, the exact time of equipment failure cannot be surely known. Then, new part(s) will be replaced when the existing ones breakdown. But the average purchasing time is still equal to the mean time between failures.



Appendix Figure 3 The extension of EOQ model for Critical spare parts

In cases where component is implied to be a necessity (or criticality), a safety stock should be issued. A new order will be purchased when spare parts are touched, and a new replenishment will be ordered during the period after the safety stock has begun being used (see Appendix Figure 3).



Appendix figure 4 The extension of EOQ model for Non-critical spare parts

In cases where a component is implied as less necessity (or non-criticality), a new order can be delayed until the spare part(s) is empty. Or new replenishment will be ordered after spare part(s) are stocked out (see Appendix Figure 4).

According to Appendix 3 and 4, the total inventory cost of both cases is the same result; therefore, the total inventory cost of the extension EOQ model is:

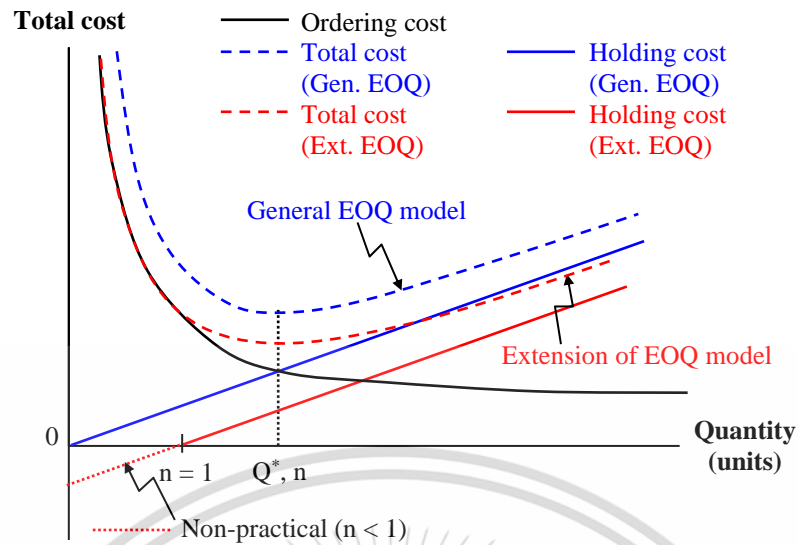
$$\begin{aligned}
 TC_{EOQ} &= S \left(\frac{k}{n} \right) + C \operatorname{Im} \cdot \left(\frac{n}{2} \right) (n-1) \left(\frac{M_{TBF}}{n} \right) \\
 &= S \left(\frac{k}{n} \right) + C \operatorname{Im} \left(\frac{n-1}{2} \right) M_{TBF}
 \end{aligned} \tag{B2}$$

DWT TC_{EOQ} to n and set it as zero

$$\text{Then: } \frac{dTC_{EOQ}}{dn} = -S \frac{k}{n^2} + \frac{CI}{2} m M_{TBF} = 0$$

$$n = \sqrt{\frac{2Sk}{C \operatorname{Im} M_{TBF}}} = \sqrt{\frac{2S}{C \operatorname{Im} \theta}} \tag{B3}$$

According to equations (B1) and (B3), the optimal purchasing lot size is also the same result. But the total inventory costs between the two models are not the same. So the thinking about the minimum total cost for the general EOQ model and the extension EOQ model can be illustrated in Appendix Figure 5.



Appendix Figure 5 Comparison (for total inventory cost) between general EOQ model and extension of EOQ model.

According to Appendix Figure 5, this figure is used for explanations about ordering cost, holding cost, and total inventory cost that are plotted against n lots (or j). The full blue line represents the holding costs, and the dot blue line represents the total costs for the general EOQ model. While the full red line represents the holding costs and the dot red line represents the total costs for the extension EOQ model, and a full black line represents the ordering cost (it is the same value for both the general EOQ model and the extension EOQ model). The lowest total inventory cost of the general EOQ model is the same as that of the extension EOQ model. At the lowest total cost for the extension EOQ model, the holding cost is not equal to the ordering cost.

For the non-practical area ($n < 1$), this is not the possibility area. This portion occurs when the lot size is less than one (or decimal point). Indeed, spare parts cannot be in the decimal point if it is claimed to be a discrete pattern (or intermittent). Or parts cannot be purchased by less than one unit (or they should be purchased in at least one lot size).

Appendix C

The comparison between LFL and EOQ model for slow moving items

According to slow-moving items, the total inventory cost of the LFL model is not the same as that of fast-moving items. Because slow-moving items always have a mean time between failures over more than one year, the total inventory cost will be determined based on the equipment's entire life (or M_{TBF}). So the total cost of the LFL model is:

$$TC_{LFL} = S \cdot k \quad (C1)$$

And the total inventory cost of the extension EOQ model is calculated on the basis of thinking about the equipment throughout its entire life (or M_{TBF}), the same as the LFL model. Then the total cost is:

$$TC_{EOQ} = S \left(\frac{k}{n} \right) + C \text{Im} \left(\frac{n-1}{2} \right) M_{TBF} \quad (C2)$$

At the break-even point $TC_{LFL} = TC_{EOQ}$

$$Sk = \frac{Sk}{n} + C \text{Im} \cdot \left(\frac{n-1}{2} \right) M_{TBF}$$

$$Sk \left(1 - \frac{1}{n} \right) = \left(\frac{C \text{Im}}{2} \right) (n-1) M_{TBF}$$

$$\left(\frac{Sk}{n} \right) (n-1) = \left(\frac{C \text{Im}}{2} \right) (n-1) M_{TBF}$$

$$\frac{Sk}{n} = \frac{C \text{Im} M_{TBF}}{2}$$

$$\text{By: } n = \sqrt{\frac{2Sk}{C \text{Im} M_{TBF}}} = \sqrt{\frac{2S}{C \text{Im} \theta}} \quad (C3)$$

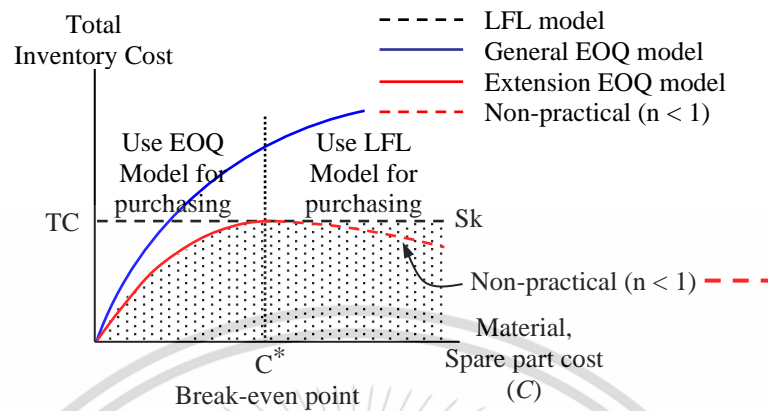
$$\text{Thus: } Sk \cdot \left(\frac{\sqrt{C \text{Im} M_{TBF}}}{\sqrt{2Sk}} \right) = \frac{C \text{Im} M_{TBF}}{2}$$

$$\sqrt{\frac{Sk C \text{Im} M_{TBF}}{2}} = \frac{C \text{Im} M_{TBF}}{2}$$

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$$\text{Then: } C^* = \frac{2Sk}{Im M_{TBF}} = \frac{2S}{Im \theta} \quad (C4)$$



Appendix Figure 6 The comparison among LFL model General EOQ model and Extension EOQ model.

According to equation (A10) and appendix figure 6, the symbol C^* is the break-even point. If the material (spare part) unit cost (C) is over the break-even point (C^*), then the lot size will be less than one. From this point forward, this is not practicable thinking. Because of the holding cost, the minus value (the other components are similarly thought of). Meaningfully, spare parts are ordered in less than one lot (it is not possible). Basically, spare parts are always replaced by m units (or one lot) for every change. Thus, spare parts have to be purchased by multiplying with m units (or n lots).

If n is equal to one lot, then there is no holding cost. Because of the new parts will be replaced all. For this case, this seemed to be purchased by applying the LFL model. When n is equal to one, the term of holding cost in equation (C4) will be waived. There is only ordering cost which is equal to the multiplication between ordering cost per one time (S) and identical equipment (k) installed in a system. Or, it is equal to $S \times k$ which conforms to LFL model. So, a case of n is less than one, roundup of n (or at least one lot) will be done. For this case, LFL model will be issued.

Regarding Appendix Figure 6, the interception and slope of the plotting for total inventory cost against spare part unit cost are shown as follows:

Recalling equation (B2), the total inventory cost of the extension EOQ model (TC_{EOQ}) can be rewritten in terms of spare part unit cost (C) as:

$$TC_{EOQ} = \left(\frac{Sk}{n} \right) + C \text{Im } M_{TBF} \cdot \left(\frac{n-1}{2} \right)$$

$$\text{By: } n = \sqrt{\frac{2Sk}{C \text{Im } M_{TBF}}}$$

$$\begin{aligned} \text{So: } TC &= \left(\frac{Sk}{\sqrt{\frac{2Sk}{C \text{Im } M_{TBF}}}} \right) + C \text{Im } M_{TBF} \cdot \left(\frac{\left(\sqrt{\frac{2Sk}{C \text{Im } M_{TBF}}} \right) - 1}{2} \right) \\ &= \left[\left(\frac{2}{\sqrt{2}} \right) \left(\sqrt{Sk \text{Im } M_{TBF}} \right) \cdot \left(\sqrt{C} \right) \right] - \frac{1}{2} (C \text{Im } M_{TBF}) \end{aligned}$$

Intercept = 0 (intercept at original point), and Slope is:

$$\text{DWT } TC_{EOQ} \text{ to } C, \text{ Then: Slope} = \frac{dTC_{EOQ}}{dC}$$

$$\text{Slope} = \frac{1}{\sqrt{2}} \left(\frac{\sqrt{Sk \text{Im } M_{TBF}}}{\sqrt{C}} \right) - \frac{1}{2} (\text{Im } M_{TBF})$$

Where: $C > 0$

Note: The case study of real equipment and the plotted graph of the total cost against the material unit cost of these formulations are shown in Chapter 4.

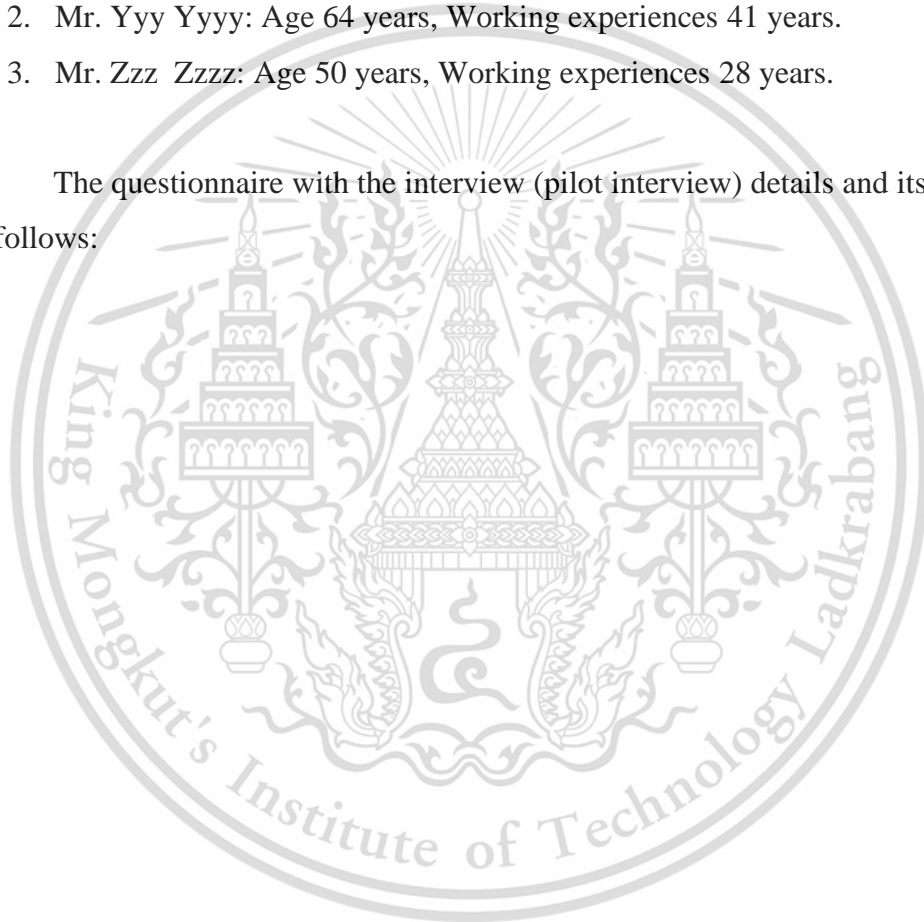
Appendix D

Pilot Interview

The specific interview format is exactly specified for experts (specialists) or those with direct experience in the maintenance of machinery or systems. The interviewee will be asked the questions which are clearly stated in a pre-defined questionnaire. The three experts interviewed include:

1. Mr. Xxx Xxxx: Age. 55 years, Working experiences 33 years.
2. Mr. Yyy Yyyy: Age 64 years, Working experiences 41 years.
3. Mr. Zzz Zzzz: Age 50 years, Working experiences 28 years.

The questionnaire with the interview (pilot interview) details and its results are as follows:



แบบสอบถามเรื่องปัจจัยที่มีผลต่อการใช้งานและการคงคลังอะไหล่
(แบบสัมภาษณ์เฉพาะผู้เชี่ยวชาญ)

ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

1. ชื่อ – สกุล

.....

2. ลักษณะงานที่ทำ – ตำแหน่งในองค์กร

.....

.....

3. ประสบการณ์ในงานที่ทำงาน

จำนวน ปี

ข้อใดต่อไปนี้ท่านคิดว่าองค์ประกอบใดต่อไปนี้คาดว่าจะส่งผลกระทบต่อการใช้งานอะไหล่และการคงคลัง

	ใช่	ไม่ใช่
1. ความต้องการของตลาด	<input type="checkbox"/>	<input type="checkbox"/>
2. ความน่าเชื่อถือของอุปกรณ์	<input type="checkbox"/>	<input type="checkbox"/>
3. ราคาอะไหล่	<input type="checkbox"/>	<input type="checkbox"/>
4. ระยะเวลาการสั่งซื้อ	<input type="checkbox"/>	<input type="checkbox"/>
5. ความสำคัญของอะไหล่ต่อระบบ	<input type="checkbox"/>	<input type="checkbox"/>
6. อัตราการเสียของชิ้นส่วนหรืออุปกรณ์ในระบบ	<input type="checkbox"/>	<input type="checkbox"/>
7. ระยะเวลาการจัดการและการขนส่งอะไหล่	<input type="checkbox"/>	<input type="checkbox"/>
8. ความซับซ้อนของการผลิตอะไหล่	<input type="checkbox"/>	<input type="checkbox"/>
9. ต้นทุนการจัดเก็บและการบริหารคลังสินค้า	<input type="checkbox"/>	<input type="checkbox"/>
10. นโยบายการซ่อมบำรุง	<input type="checkbox"/>	<input type="checkbox"/>
11. การวางแผนการซ่อมบำรุง	<input type="checkbox"/>	<input type="checkbox"/>
12. คุณภาพของอะไหล่	<input type="checkbox"/>	<input type="checkbox"/>
13. อายุการใช้งานของอะไหล่	<input type="checkbox"/>	<input type="checkbox"/>
14. แนวโน้มเทคโนโลยี	<input type="checkbox"/>	<input type="checkbox"/>
15. ความเสี่ยงและอุปสงค์ที่ไม่แน่นอนของอะไหล่	<input type="checkbox"/>	<input type="checkbox"/>
16. ความล้าสมัยของอะไหล่	<input type="checkbox"/>	<input type="checkbox"/>

ขอให้ท่านเรียงลำดับความสำคัญของปัจจัยที่มีต่อการใช้งานจาก 16 หัวข้อท่านได้ตอบก่อนหน้านี้เป็นโดยเลือกปัจจัยที่มีความสำคัญมาก 3 อันดับแรก (มากอันดับ 1 (ส่งผลมากที่สุด), มากอันดับ 2, มากอันดับ 3)

อันดับที่ 1 ข้อ

อันดับที่ 2 ข้อ

อันดับที่ 3 ข้อ

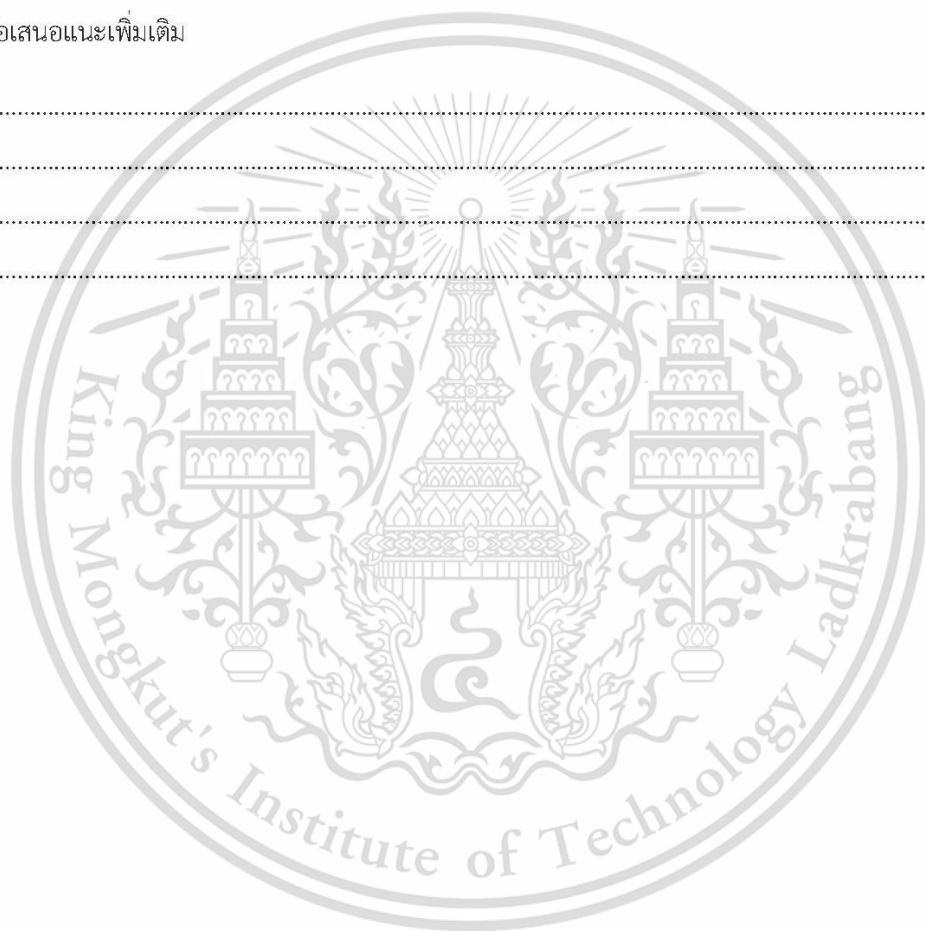
ข้อเสนอแนะเพิ่มเติม

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แบบสอบถามเรื่องปัจจัยที่มีผลต่อการใช้งานและการคงคลังอะไหล่
(แบบสัมภาษณ์เฉพาะผู้เชี่ยวชาญ)

ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

1. ชื่อ - สกุล

2. ลักษณะงานที่ทำ - ตำแหน่งในองค์กร

ที่ปรึกษาควบคุมงานติดตั้งระบบไฟฟ้ากรเป็นสมทบและระบบ
ตรวจสอบระบบเปิดระบบ / ผู้เชี่ยวชาญระบบไฟฟ้ากรเป็นสมทบ

3. ประสบการณ์ในงานที่ทำงาน

ท่าอากาศยาน

จำนวน 33 ปี

ข้อใดต่อไปนี้เป็นที่ท่านคิดว่าองค์ประกอบใดต่อไปนี้จะส่งผลกระทบต่อการใช้งานอะไหล่และการคงคลัง

	ใช่	ไม่ใช่
1. ความต้องการของตลาด	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2. ความน่าเชื่อถือของอุปกรณ์	<input checked="" type="checkbox"/>	<input type="checkbox"/>
3. ราคาอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4. ระยะเวลาการสั่งซื้อ	<input checked="" type="checkbox"/>	<input type="checkbox"/>
5. ความสำคัญของอะไหล่ต่อระบบ	<input checked="" type="checkbox"/>	<input type="checkbox"/>
6. อัตราการเสียของชิ้นส่วนหรืออุปกรณ์ในระบบ	<input checked="" type="checkbox"/>	<input type="checkbox"/>
7. ระยะเวลาการจัดการและการขนส่งอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
8. ความซับซ้อนของการผลิตอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
9. ต้นทุนการจัดเก็บและการบริหารคลังสินค้า	<input checked="" type="checkbox"/>	<input type="checkbox"/>
10. นโยบายการซ่อมบำรุง	<input checked="" type="checkbox"/>	<input type="checkbox"/>
11. การวางแผนการซ่อมบำรุง	<input checked="" type="checkbox"/>	<input type="checkbox"/>
12. คุณภาพของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
13. อายุการใช้งานของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
14. แนวโน้มเทคโนโลยี	<input checked="" type="checkbox"/>	<input type="checkbox"/>
15. ความเสี่ยงและอุปสงค์ที่ไม่แน่นอนของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
16. ความล้าสมัยของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>

ขอให้ท่านเรียงลำดับความสำคัญของปัจจัยที่มีต่อการใช้งานจาก 16 หัวข้อท่านได้ตอบก่อนหน้านี้เป็นโดยเลือกปัจจัยที่มีความสำคัญมาก 3 อันดับแรก (มากอันดับ 1 (ส่งผลมากที่สุด), มากอันดับ 2, มากอันดับ 3)

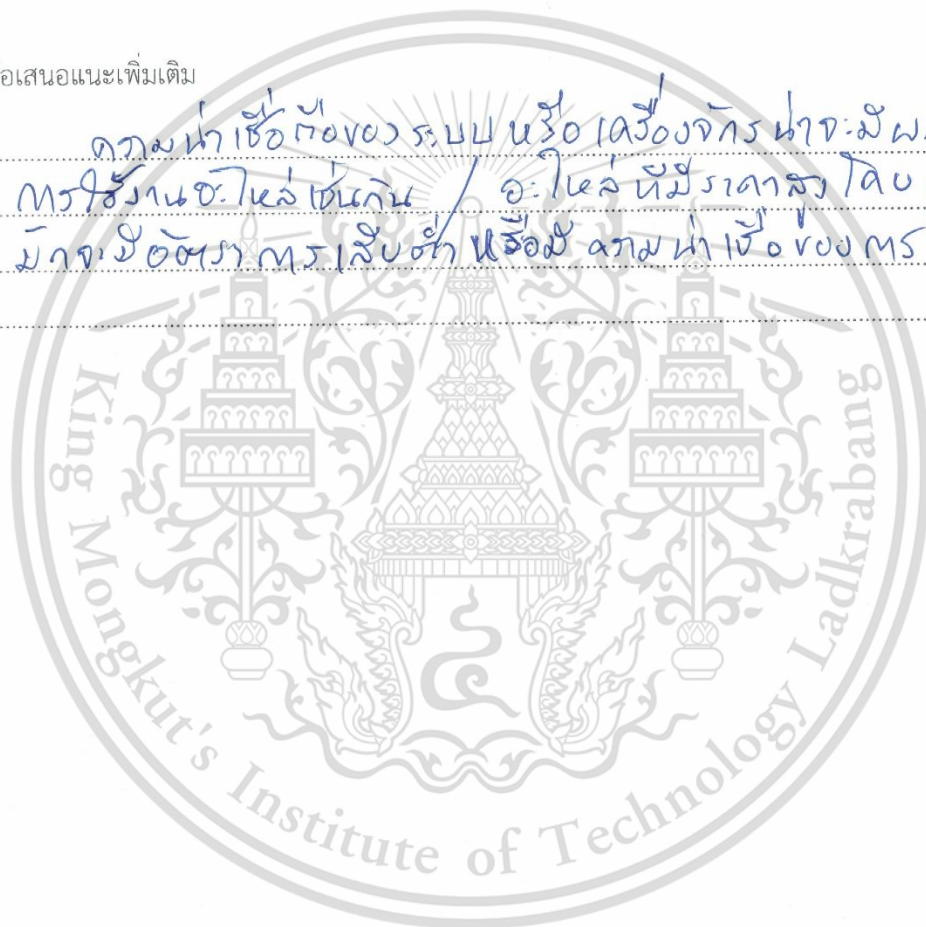
อันดับที่ 1 ข้อ 5 ตามลำดับของอะไหล่ต่อระบบ

อันดับที่ 2 ข้อ 6 อัตราการเสื่อมของชิ้นส่วนหรืออุปกรณ์ในระบบ

อันดับที่ 3 ข้อ 3 ราคาอะไหล่

ข้อเสนอแนะเพิ่มเติม

ควรนำชื่อของระบบ หรือ เครื่องจักร มาจะสัมพันธ์
 การใช้งานอะไหล่ต้นเกิน / อะไหล่ที่มีราคาสูง โดยส่งออกมา
 มากจะอัตราการผลิต หรือ นำตามนำชื่อของเครื่องจักร



แบบสอบถามเรื่องปัจจัยที่มีผลต่อการใช้งานและการคงคลังอะไหล่
(แบบสัมภาษณ์เฉพาะผู้เชี่ยวชาญ)

ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

1. ชื่อ - สกุล

2. ลักษณะงานที่ทำ - ตำแหน่งในองค์กร

งานบำรุงรักษาระบบลิฟต์และระบบไฟฟ้าลิฟต์ในรพ.ที่อภิตถาศูนย์/
BHS ' specialist

3. ประสบการณ์ในงานที่ทำงาน

จำนวน 41 ปี

ข้อใดต่อไปนี้ท่านคิดว่าองค์ประกอบใดต่อไปนี้จะส่งผลกระทบต่อการใช้งานอะไหล่และการคงคลัง

	ใช่	ไม่ใช่
1. ความต้องการของตลาด	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2. ความน่าเชื่อถือของอุปกรณ์	<input checked="" type="checkbox"/>	<input type="checkbox"/>
3. ราคาอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4. ระยะเวลาการสั่งซื้อ	<input checked="" type="checkbox"/>	<input type="checkbox"/>
5. ความสำคัญของอะไหล่ต่อระบบ	<input checked="" type="checkbox"/>	<input type="checkbox"/>
6. อัตราการเสียของชิ้นส่วนหรืออุปกรณ์ในระบบ	<input checked="" type="checkbox"/>	<input type="checkbox"/>
7. ระยะเวลาการจัดหาและการขนส่งอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
8. ความซับซ้อนของการผลิตอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
9. ต้นทุนการจัดเก็บและการบริหารคลังสินค้า	<input checked="" type="checkbox"/>	<input type="checkbox"/>
10. นโยบายการซ่อมบำรุง	<input checked="" type="checkbox"/>	<input type="checkbox"/>
11. การวางแผนการซ่อมบำรุง	<input checked="" type="checkbox"/>	<input type="checkbox"/>
12. คุณภาพของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
13. อายุการใช้งานของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
14. แนวโน้มเทคโนโลยี	<input checked="" type="checkbox"/>	<input type="checkbox"/>
15. ความเสี่ยงและอุปสงค์ที่ไม่แน่นอนของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
16. ความล้าสมัยของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>

ขอให้ท่านเรียงลำดับความสำคัญของปัจจัยที่มีต่อการใช้งานจาก 16 หัวข้อท่านได้ตอบก่อนหน้านี้เป็นโดย
เลือกปัจจัยที่มีความสำคัญมาก 3 อันดับแรก (มากอันดับ 1 (ส่งผลมากที่สุด), มากอันดับ 2, มากอันดับ 3)

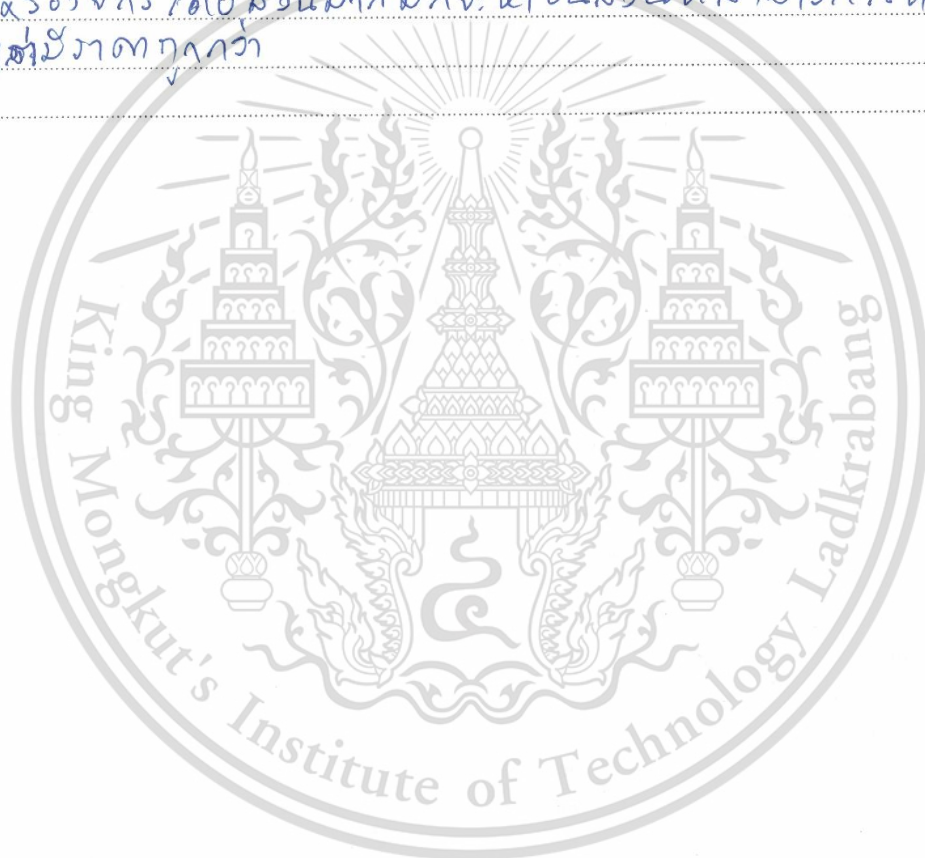
อันดับที่ 1 ข้อ 5 ความสำคัญของอินเทอร์เน็ต

อันดับที่ 2 ข้อ 6 อัตราการเติบโตของชิ้นส่วนประกอบในระบบ

อันดับที่ 3 ข้อ 3 ราคา: ไม้

ข้อเสนอแนะเพิ่มเติม

ราคา: ไม้ที่แพงมาก ปิดระบบเครือข่ายบริษัท
เครื่องจักรโดยสิ้นเชิง: ไม้ชิ้นส่วนนี้สามารถใช้งานได้
แล้วมีราคาถูกกว่า



แบบสอบถามเรื่องปัจจัยที่มีผลต่อการใช้งานและการคงคลังอะไหล่
(แบบสัมภาษณ์เฉพาะผู้เชี่ยวชาญ)

ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

1. ชื่อ - สกุล

2. ลักษณะงานที่ทำ - ตำแหน่งในองค์กร

งานบริหารระบบไฟฟ้า (แล้ว) ความเป็นที่ปรึกษาท่าอากาศยาน /
Maintenance Manager

3. ประสบการณ์ในงานที่ทำงาน

จำนวน 28 ปี

ข้อใดต่อไปนี้เป็นท่านคิดว่าองค์ประกอบใดต่อไปนี้จะส่งผลกระทบต่อการใช้งานอะไหล่และการคงคลัง

	ใช่	ไม่ใช่
1. ความต้องการของตลาด	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2. ความน่าเชื่อถือของอุปกรณ์	<input checked="" type="checkbox"/>	<input type="checkbox"/>
3. ราคาอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4. ระยะเวลาการสั่งซื้อ	<input checked="" type="checkbox"/>	<input type="checkbox"/>
5. ความสำคัญของอะไหล่ต่อระบบ	<input checked="" type="checkbox"/>	<input type="checkbox"/>
6. อัตราการเสียของชิ้นส่วนหรืออุปกรณ์ในระบบ	<input checked="" type="checkbox"/>	<input type="checkbox"/>
7. ระยะเวลาการจัดหาและการขนส่งอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
8. ความซับซ้อนของการผลิตอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
9. ต้นทุนการจัดเก็บและการบริหารคลังสินค้า	<input checked="" type="checkbox"/>	<input type="checkbox"/>
10. นโยบายการซ่อมบำรุง	<input checked="" type="checkbox"/>	<input type="checkbox"/>
11. การวางแผนการซ่อมบำรุง	<input checked="" type="checkbox"/>	<input type="checkbox"/>
12. คุณภาพของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
13. อายุการใช้งานของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
14. แนวโน้มเทคโนโลยี	<input checked="" type="checkbox"/>	<input type="checkbox"/>
15. ความเสี่ยงและอุปสงค์ที่ไม่แน่นอนของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>
16. ความล้าสมัยของอะไหล่	<input checked="" type="checkbox"/>	<input type="checkbox"/>

ขอให้ท่านเรียงลำดับความสำคัญของปัจจัยที่มีต่อการใช้งานจาก 16 หัวข้อท่านได้ตอบก่อนหน้านี้เป็นโดย
เลือกปัจจัยที่มีความสำคัญมาก 3 อันดับแรก (มากอันดับ 1 (ส่งผลมากที่สุด), มากอันดับ 2, มากอันดับ 3)

อันดับที่ 1 ข้อ 5 ความเสถียรของ: ไลน์เตอร์, พี
อันดับที่ 2 ข้อ 6 อัตราการสแกนของชิ้นส่วนเชิงอุปกรณ์ในรูป, พี
อันดับที่ 3 ข้อ 3 ราคา: ไลน์

ข้อเสนอแนะเพิ่มเติม

ไม่มี



AUTHOR BIOGRAPHY

- Name Mr. Sakon Wongmongkolrit
- Date of Birth 16 June 1969
- Address 189/235 Property perfect place phase 6, Soi Ladkrbang 20/3, Onnut-Ladkrabang Road, Tambol Rachatewa, Bangplee, SamutPrakan, 10540, Thailand
- Education
- Bachelor of Engineering (Electrical Engineering), Prince of Songkla University, Hat-Yai campus, Songkla, 1991
 - Master of Science (Economics), Kasetsart University, Bangkhen campus, Bangkok, 2000.
 - Bachelor of Science (Occupational Health and Safety), Sukhothai Thammathirat, Pakkret campus, Nonthburi, 2015
- Work Experience
- Baggage Handling System Manager/ICT Specialist at Team Consulting Engineering and Management Public Company Limited, 2017 – Present