

Research on Equipment and Spare Parts Management Based on Theory of Constraints

Yan Ye

Doctoral candidate, Department of Industrial Engineering and Management, Shanghai Jiao Tong University, Shanghai 200030, China

Institute of Industrial Engineering, Zhejiang University of Technology, Hangzhou 310032, China
yeyna@sjtu.edu.cn

ABSTRACT

On the basis of analyzing the relationship between the equipment system and spare parts inventory, this paper proposes two-level equipment and spare parts system management based on the Theory of Constraints. From the system point of view and according to the Theory of Constraints, the manufacturing organization identifies bottleneck equipments in equipment system and makes the bottleneck equipments operate continuously and effectively on the basis of two important aspects of materials supply and spare parts supply. Finally, the spare parts' ABCD-TOC inventory classification and control method based on the Theory of Constraints is introduced. This method classifies spare parts according to different demands of bottleneck and non-bottleneck equipments, technical rules of spare parts failure and waste and purchase characteristics. Then the suitable control strategies for each class are adopted to focus on bottleneck equipments without sacrificing the spare parts supply for non-bottleneck equipments, as well as to reduce inventory investment.

Key words: Theory of constraints, Equipment management, Spare parts management, Inventory

1. INTRODCUTION

During the past two decades, as a result of serious global competition, the modern company depends on the high-effective equipments increasingly to strengthen its competitive capacity. And along with the development and progress of science and technology, equipments tend to the large-scale, high precision and complexity and their automation degree has enhanced. The maintenance expenses and fault loss of equipments account for an increasing fraction of the production costs. It has a great effect on the competitive ability that companies keep and improve equipment utilization. But equipment utilization is decided not only by its reliability and maintainability but also by spare parts supply which is the essential physical foundation^[1]. The spare parts management also is an important part in management activities of company equipment.

Spare parts inventories differ from other manufacturing inventories in several ways. First, the functions are different. Raw material inventories exist to offer the required raw materials for production. Work-in-process (WIP) inventories exist in order to smooth out irregularities in production flow. Finished product inventories exist to provide a source of products for delivery to customers and are designed to protect against irregularities in differences in quality levels, scheduling problems, and other well-known production characteristics. The function of spare parts inventories, however, is to assist a maintenance staff in keeping equipment in operating condition and promoting continuous production process. Second, WIP and final product inventories can be increased or decreased by changing production rates and schedules, improving

quality, etc. Spare parts inventory levels, however, are largely a function of how equipment is used and how it is maintained. Therefore the spare parts inventory and the status of equipments promote mutually^[2].

For avoiding excessively long equipment downtime due to lack of spare parts required and corresponding loss of time, output and profit, companies always prepare adequate spare parts to promptly supply. However, inventory is expensive especially when spare parts are stocked too much and the total investment in spare parts is very large. Therefore there is the conflict of spare parts inventories, equipment operation and investments for the goals of enhancing competitive ability and realizing high profitability (see Fig.1). Managing and controlling effectively equipment and spare parts system may be of vital significance to balance these goals of maintaining high equipment availability, minimizing inventory investment and attaining high profitability.

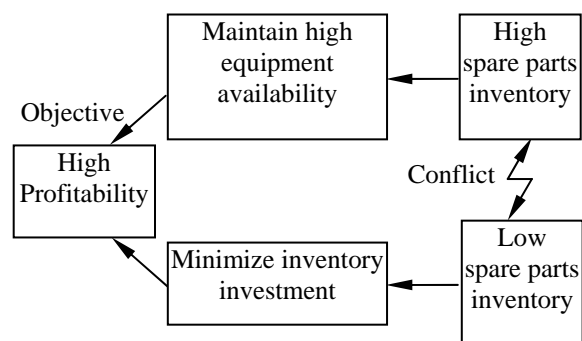


Fig. 1. Relationship between spare parts inventory and equipment system

The Theory of Constraints (TOC) on a basis of

Optimized Production Technology (OPT) was expounded by Israeli physicist Eliyahu M. Goldratt (1986), which was developed from initial manufacturing management principle to "Thinking Process" of solving problems logically and systematically. The theory was applied to many fields beyond production management [3].

The organization of this paper is as follows. The basic concept of TOC is sketched in Section 2. Next, Section 3 proposes two-level equipment and spare parts system management based on the Theory of Constraints. On a basis of analyzing two important supporting resources for equipment operation, the spare parts' ABCD-TOC inventory classification and control method is introduced. A summary and concluding remark is given in the final section.

2. BASIC PRINCIPLE OF TOC

The Theory of Constraints considers the production and operations of manufacturing organizations from the entire system point of view. Goldratt argues that the goal of a company is to make money and develops a different set of measurements which express the goal: throughput, inventory and operational expense. They are defined as follows. Throughput is the rate at which the system generates money through sales. Inventory is all the money that the system has invested in purchasing things which it intends to sell. Operational expense is all the money the system spends in order to turn inventory into throughput [4].

In any system, if any link output is decided by the outputs of one or several stages before it, the link with the least output determines the output level of the whole system, that is, the strength of a chain is determined by the weakest link. The link is called a constraint and also a bottleneck. TOC is the management idea and principle that help companies to identify, exploit and eliminate constraints and then to maximize throughput and reduce inventory and operational expense. Companies can apply the Theory of Constraints through five-step focusing process as follows [4]: (1) Identify the system's constraint(s); (2) Decide how to exploit the system's constraint(s); (3) Subordinate everything else to the above decision; (4) Elevate the system's constraint(s); (5) If in the previous steps a constraint has been broken, go back to step 1, but do not allow inertia to cause a system's constraint.

The process of implementing these five steps is also three steps thinking process: "what to change?", "what to change to?" and "how to cause the change?". Then, companies can achieve their goal by focusing on the key point-the constraint and can promote continuous improvement because the constraint is not static but dynamic and changing.

3. TWO-LEVEL EQUIPMENT AND SPARE PARTS SYSTEM MANAGEMENT BASED ON TOC

3.1 General Framework

Market competition is more and more fierce and customers' demands for diversified products tend to enhance, which cause shorter product life cycle and decrease product quantities of each order [5]. For abstaining from risks, companies do not purchase or update expensive production resources easily and exploit the utilization of existing equipments as far as possible. So the overall productivity appears insufficient in the growing and mature period of product life cycle. According to TOC, we regard several or a set of equipments producing one kind of product or a series of products as an equipment system. In this system if any segment (the equipment or equipment group) hinders the overall system to increase throughput or decrease inventory and operational expense, the segment is a constraint, that is, the bottleneck equipment. The bottleneck equipment whose capacities are not sufficient restricts the system throughput and decides the degree of other non-bottleneck resources utilization. As the physical base of equipment system, the main task of spare parts inventory is to assure all equipments in good condition. A spare part, especially for bottleneck equipments, is called the bottleneck spare part so long as it affects the system throughput, which is the important point of the spare parts management. The structure of two-level TOC-based equipment and spare parts system management is depicted in Fig. 2.

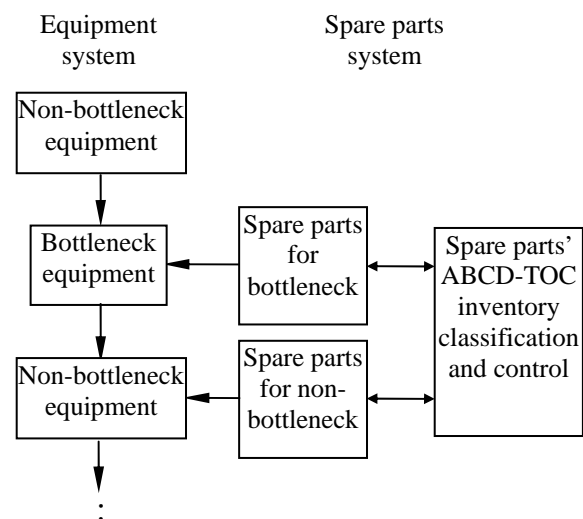


Fig. 2. Two-level equipment and spare parts system management based on TOC

3.2 TOC-based equipment system management

The fundamental task of TOC-based equipment system management is to identify the bottleneck of the entire system and manage the bottleneck and resources before

and after it to maximize system throughput. The bottleneck equipment of the equipment system is the equipment or equipment group whose actual capacities are smaller than or equal to production loads (demands), that is, the system's constraint is the equipment experiencing the highest load rate. The equipment load rate is defined as its duty to its available capacity during the plan period, which is given by equation (1).

$$L_t = \frac{\sum Q_t S}{TA_t} \times 100\% \quad (1)$$

Where L_t is the equipment load rate over the plan period t . Q_t represents quantities of each product that the equipment should produce during t . S is defined as the planned time standard of each produce. T indicates the institutional time of the equipment during t . A_t is the probability of equipment availability which comprehensively reflects reliability and maintainability.

After the bottleneck equipment is identified, how to make full use of the equipment is the first problem that needs to be solved. Considering the direct resources required to produce products, we may establish the material buffer to make equipment run continuously. The buffer is often classified into inventory buffer and time buffer. Inventory buffer is a kind of insurance Work-in-processes. Time buffer is required materials handed over advancing a period of time from the planned time to eliminate influences of stochastic fluctuation in production processing, which is measured by processing time length of bottleneck. On the other hand, from the technical resources supporting equipment system viewpoint, we should increase the overall equipment effectiveness (OEE) and reduce unscheduled downtime especially caused by equipment failure as far as possible, which depends on maintenance resources such as maintenance men, maintenance tools and supply of spare parts. However, compared with the service men and tools, spare parts investment is higher and lack of spare parts is the most main influence factor frequently. Thus, this paper introduces TOC-based spare parts inventory management to keep equipment, especially bottleneck equipments, run well and maintenance efficiency as well as reduce costs.

3.3 TOC-based spare parts inventory management

Generally companies have large quantities of and many types or specifications of spare parts inventories. To manage inventories through Stocktaking, placing and accepting orders endlessly would be time-consuming. Then companies manage spare parts inventories through classification.

Dickie proposed ABC classification method ^[6] in 1951. The purpose of this method is to measure and classify the degree of importance and concentration of inventory

items in terms of the value of items and Pareto principle. The method is simple and wieldy and so is adopted by many companies for a long time. However, the value of spare parts has no inevitable relations with their influences on the equipments and production.

In accordance with the special characteristics of spare parts inventory, 3A inventory control method ^[7] classifies spare parts into 27 different kinds of rank from AAA to CCC according to the important degree of spare parts to equipments. Considering actual operations conditions of equipments, the method decides essentiality and specific rank and order of each spare part according to three aspects: equipment and its components belonging to, production load enduring and its effect on product quality. Then the method adopts the corresponding control method. Guo Zhimin et al. ^[7] offer ABCD inventory control method in terms of several criterions such as influence of spare parts on productive condition, the rules of fault and wasting, and agility of supply channels. Dekker et al. ^[8] classify demand for spare parts into critical and non-critical demands according to the influence caused by the disabled equipment that a spare part is installed. In this paper we analyze classification and control methods of spare parts from the system point of view, not only from single equipment viewpoint, and according to the Theory of Constraints that to our knowledge have not been discussed in the literature so far. The method is called spare parts' ABCD-TOC inventory classification and control method which classified spare parts into four classes.

A class includes special spare parts that are installed to the bottleneck equipments and can not be checked in advance or their failure and wear time can not be forecast, and that are installed to the non-bottleneck equipments and supplied by few providers and/or with long purchase lead time (such as purchased from abroad). Because an hour lost at the disabled bottleneck equipment is an hour out of the entire system and part of these spare parts are only used by the bottleneck equipment, this type is very important. Compared to the bottleneck equipment, non-bottleneck equipment always has idle time. But if purchasing time exceeds idle time, non-bottleneck equipment will affect production system throughput. Thus, this class may be called the bottleneck spare parts and is controlled by an $(S-I, S)$ policy, or equivalently, by a base stock policy ^[2]. The base stock S is defined as maximal possible consumption during an order lead time. Concretely, it can be calculated through adding historical average consumption over an order lead time to a suitable safety quantity. The safety quantity is achieved by multiplying fluctuation average of historical consumption by certain safe factor as a kind of buffer which is considered comprehensively according to production task, usage years of equipments, etc. Stock level will be inspected and checked after spare parts are used or continuously. When the actual valid inventory level is lower than S ,

one purchase order should be placed with the order quantities which is decided by subtracting the current stock level from S .

B class includes spare parts with predictable replacement time used by bottleneck and/or non-bottleneck equipments. Companies can forecast the time when need to replace this type spare parts through checking in advance, tracking and analyzing their conditions in time. Or they track daily usage of these spare parts in a long time and statistically analyze the rule of their fault and waste to estimate their replacement time cycle. When companies have predicted the replacement need during equipment operating period, they should estimate the earliest time and advance several days according to specific situations of the time and then order ahead of purchase lead time. Thus companies can supply required spare parts timely while reduce occupied time and fund of inventory.

C class is the special spare parts with many supply channels and/or short purchase lead time which can be sucked by idle time of equipments. For avoiding depletion in stock and reducing investment, this type can be controlled by zero inventory policy, that is, these spare parts are not stocked. When production department demands the spare parts, it applies for the purchase immediately. Then purchase department orders immediately from suppliers. After spare parts arrive, purchase department checks and accepts and warehouse registers. The spare parts are sent to the production center directly.

All general spare parts fall into D type. The general spare parts are installed at some even all equipments, so their reflections of production and maintenance change are not obvious. When a general spare part is requested by bottleneck and non-bottleneck equipments synchronously, it must meet bottleneck first that helps to assure and increase system throughput. This type has many kinds of spare parts whose usages and investments are large. The class can be controlled by periodic review (t, s, S) inventory policy^[9] where t presents fixed review period, s reorder point, S maximum stock level. We estimate s by computing consumption of each spare part during purchase lead time after examining its daily average usage over a long period of time, and take S as three or four times of s . Suitable t can be set according to the spare part with the fastest consumption rate in this type as long as all spare parts of the type are not short during the period t . Inventory levels of these spare parts are checked and compared to s every other t . If inventory level is lower than s , the spare part would be ordered and order quantity is the balance of S and current level. If the level is larger than s , there is no any order. This type of periodic review reduces massive work as a result of continuous review and keeps proper inventory level without short of spare parts and with lower investment.

It is worth explaining that the classification of A, B, C and D classes is not always changeless but dynamically adjusted and transformed one another. For example, after some measures for improving equipments capacity are taken constantly, some bottleneck equipments change to non-bottlenecks and then some spare parts of A class are transformed into C class. When more advanced statistical analysis technology make the fault and waste rule of equipment and spare parts learned, some A class spare parts may be classified into B class.

4. CONCLUSION

This paper analyzes the relationship between the equipment system and spare parts inventory and proposes two-level equipment and spare parts system management based on the Theory of Constraints. From the system point of view and according to the Theory of Constraints, the company identifies bottleneck equipments in equipment system and makes the bottleneck equipments operate continuously and effectively. Companies can take measures such as buffers to supply enough materials. However, the same important thing that companies should do is to supply enough spare parts timely. So the spare parts' ABCD-TOC inventory classification and control method based on the Theory of Constraints is introduced. This method classifies the spare parts according to different demands of bottleneck and non-bottleneck equipments, technical rules of spare parts failure and wasting and purchase characteristics. Then the suitable control strategies for each class are adopted to focus on getting bottleneck equipment operate without sacrificing the spare parts supply for non-bottleneck equipments, as well as to reduce the occupied fund of inventory. This paper explores the management of equipment system and spare parts inventory from the entire system viewpoint and it provides the theory and application values for modern companies.

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