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Spare Parts Inventory Management Using Quantitative and Qualitative Classification

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Abstract This paper focuses on the spare parts inventory management of a maintenance provider of the health sector, where the commitment to ensure the agreed customer service level and the guarantee of maximum availability of the devices are relevant issues. Spare parts inventory management means handling with unpredictable consumption, since in most cases, it is impossible to know in advance when a specific spare part will be necessary or the needed amount. Determining an adequate inventory management policy for spare parts, specifically for unplanned maintenance operations is essential to provide the contracted service level. Considering that the criticality of a spare part has consequences regarding the availability of an equipment and service level agreement, the spare parts were classified in terms of quantity, value of usage and criticality. Based on this classification, differentiated service levels and inventory management policies were adopted for each group.

Keywords: Inventory management; spare part; ABC analysis; criticality analysis

1 Introduction

This paper is motivated by a real case study concerning the spare parts inventory management derived from unplanned maintenance activities in a maintenance provider, in the health sector. The importance of the subject in a maintenance en-

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vironment, as well as the practical application of the defined method were essential elements in the development of the spare part inventory management model.

In order to support and achieve competitive advantage and create added value for the customers (Porter, 1985) an efficient inventory management is essential in any maintenance department. The main objective of an inventory management system is to achieve the requested service level with the minimum inventory investment and administrative costs (Huiskonen, 2001). Regarding the main maintenance types, different inventory control practices are needed for preventive maintenance and unplanned maintenance (Celebi, 2008). Kennedy et al. (2002) attend that for preventive or scheduled maintenance, the demand for spare parts is predictable. It may in this case be possible to order parts to arrive just in time for use. For unplanned maintenance, the consequences of stock out often include production loss with significant costs and some kind of safety stock policy is necessary.

It should also be considered that the inventory planning of spare parts differ from other materials, since the service levels may be high and the demand for spare parts may be extremely sporadic and difficult to forecast (Huiskonen, 2001). The spare parts inventory management consists basically in establishing a balance between having or not having a spare part in stock which should be based on economic aspects and the customer service level.

Another approach given in the literature is that spare parts are often managed by applying general inventory management principles which are independent on the specific characteristics of spare parts (Huiskonen, 2001). For example, Dekker et al. (1998) define the criticality of an equipment as its importance to sustain the production in a safe and efficient way. According to De Felice et al. (2014), as the spare parts have different importance for the safe operation of a device, different inventory management policies should be adopted for each spare part group. Our approach uses this perspective and restrictions concerning the compliance with the contracted customer service level and assurance of the maximum availability of the spare parts. The higher availability of spare parts improves significantly the service level, increasing the inventory costs. Insufficient stocks can lead to high downtimes of the equipment and excessive stock may increase the inventory costs and operating costs. As these factors are critical in efficient inventory management, it is important to have a detailed analysis of all the conditions that affect the logistics of spare parts in order to make the right decisions and apply the adequate inventory management policy.

Bošnjaković (2010) proposes a quantitative and qualitative classification of the spare parts in groups according to their value of usage, frequency of usage and criticality. Afterwards, the adequate inventory management policy should be defined based on the resulting combination. Following Bošnjaković (2010), this study develops a methodology based on a quantitative and qualitative classification for spare parts in groups, proposing an inventory management policy for each spare part group of the classification. This is established on classifying the spare parts in groups according to their value of usage, quantity of usage and criticality.

The objective of this approach is to minimize inventory management costs and to ensure the agreed customer service level.

The remainder of this paper is organized as follows. Next section describes the methodology used and the results achieved. Finally, last section summarizes the paper findings.

2 Methodology

The case study is carried out in a maintenance department with a decentralized technical team, distributed by geographical area. In each acting area, the technician is provided with a car where the whole spare parts stock is stored. According to the agreed service level contracted with the customers, each technician has to solve any unplanned maintenance occurred within a time frame of 24 hours. This issue may possibly lead to excessive stock at the technician side, since no one wants to be affected by a stock out of a spare part. This stock out situation can also lead to critical downtimes of an equipment at the customer side.

Regarding the supply of spare parts it should be mentioned that only one supplier is available and any purchase order has to be placed when needed, once a week in a specific day by the technical team. The lead time is constant and equal to 7 days.

In order to suggest a solution for the spare parts inventory stock management for each technician, an evaluation of the current inventory management costs was done and a methodology to support the spare parts supply decision was developed, by assuring the minimization of the inventory management costs and the fulfilment of the contracted customer service level.

2.1 Inventory Management Costs

The inventory management is strongly influenced by the nature of demand, lead time and costs. As these variables interact with each other, determining the efficiency and effectiveness of the inventory system, it is important to calculate the inventory management costs in the actual context, in order to compare them with the resulting costs derived from the proposed inventory management policy. The annual total relevant inventory management costs have been calculated based on the acquisition cost, the ordering costs, stock out costs and the holding costs due to regular and safety stock, by the model (1.1) (Ballou, 2004). We estimate that the stock out costs depend on the expected number of cycles with stock out.

$$TC = d \cdot c + F_0 \cdot \frac{\bar{d}}{Q} + F_1 \cdot c \left(\frac{Q}{2} + SS \right) + F_2 \cdot n_r \quad (1.1)$$

We shall use the following notation:

TC	Total inventory cost
\bar{d}	Average annual demand
c	Item value
F_0	Ordering cost per order
Q	Order quantity
F_1	Annual inventory holding cost (percent of item value per year)
F_2	Cost per cycle with stock out
n_r	Number of cycles with stock out per year

2.2 Combining the Cross ABC and Criticality Analysis

The cross ABC analysis is combined with the criticality analysis (Bošnjaković, 2010; De Felice et al., 2014) to classify the 1060 spare parts in 27 groups. The cross ABC analysis allows a more efficient management of the inventory, since it simplifies the analysis and identification of spare parts with the highest quantity of usage and value of usage, besides it constitutes an asset in the qualitative evaluation of inventory. Firstly, the spare parts are classified by the quantity of usage into A, B and C classes. Afterwards, the spare parts are classified in the three classes according to the value of usage.

According to the criticality analysis the spare parts are classified into three categories based on the impact of the consequences in the operation of the customer device: Vital, Essential and Desirable. Vital spare parts are those whose stock out causes the highest impact, the device may not work without the spare part and does not allow the medical care. Essential spare parts cause some loss, affecting the quality of service, however the machine may wait for a small period of time, as the absence of that spare part does not inhibit the operation of the medical device. Therefore, the device is still operational, but without some of its functions. Desirable spare parts are those whose the lack of items has no great interference or influence on the operation of the device. The combination of the three analysis leads to a total of 27 groups, that may be represented in a three dimensional graphic, as shown in Fig. 1.

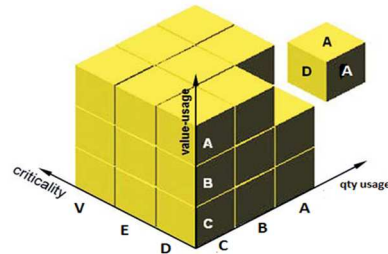


Fig. 1 3D graphic of cross ABC and criticality analysis (adapted from Bošnjaković (2010))

Although the combination of cross ABC and criticality analysis is essential for the determination of the inventory management policies, it does not identify by itself the appropriate inventory management model for each group of spare parts. The information given by cross ABC and criticality analysis supports the definition of the inventory policy and the service levels adopted for each spare parts group. Thus, the service level should increase or reduce depending on the significance given to each spare part.

2.3 Inventory Management Policies Determination

In order to clarify the inventory management policies to apply to each group, in the three dimensional model, Table 1 identifies the inventory management policies as well as the customer service level which should be adopted for spare parts in each group which are constrained by the customer contract agreement. The customer service level is the probability of no stock out per order cycle.

Table 1 Inventory management policies and service level of the 27 groups

Group	Service level	Group	Service level	Group	Service level	Inventory Management Policy to be implemented	
AAV	99%	ABV	99%	ACV	99%	Adjusted continuous revision (Q* , R)	
BAV	99%	BBV	99%	BCV	99%		
CAV	95%	CBV	99%	CCV	99%		
AAE	95%	ABE	95%	ACE	95%		
BAE	95%	BBE	95%	BCE	95%		
CAE	90%	CBE	90%	CCE	90%		
AAD	90%	ABD	90%	ACD	90%		
BAD	-	BBD	-	BCD	-		To be ordered when needed
CAD	-	CBD	-	CCD	-		

Excluding spare parts from group CAV, a service level of 99% was defined for all the spare parts of groups with Vital criticality, since the lack of any of these parts would not allow the availability of a device for medical operation. Regarding the spare parts from CAV group, a service level of 95% was defined as these parts have low quantity of usage but high value of usage. The spare parts of the CAV group represent a higher investment, thus it is acceptable to reduce the service level.

For the spare parts of group with Essential criticality, AAE, ABE, ACE, BAE, BBE and BCE, a service level of 95% was defined, assuming a risk of stock out of 5% and considering that the lack of spare parts of this group does not hinder the operation of the medical device. For the spare parts from groups CAE, CBE e

CCE, a service level of 90 % was defined given their lower demand, reducing the total inventory cost.

Regarding the spare parts from Desirable group, a service level of 90% was assigned to the spare parts of groups AAD, ABD and ACD, since these parts are characterized by a higher quantity of usage, contributing to a better technical performance. Furthermore, it avoids the need to wait for a next order to perform the maintenance intervention.

Regarding the inventory management policy, the spare parts from groups with medium and low quantity of usage (BAD, BBD, BCD, CAD, CBD and CCD) should be ordered only when needed. These spare parts can be managed through the implementation of a Kanban system. Through visual management, Kanban provides simple and intuitive indications of the stock situation, triggering purchase orders when the stock reaches a certain level or amount corresponding to the reorder point. For the remaining groups of the classification, the spare parts should be managed through the continuous review model with a small adjustment, since the purchase orders may only be placed once a week, which is equivalent to continuous review policy, discussed in the next section.

2.4 Adjusted Continuous Review Policy

Consider an inventory problem for a single installation (single-echelon) where items can be handled independently with discrete stochastic demand and constant replenishment lead time. Additionally, possible stock outs can occur and the quantity discounts are not allowed. As the demand is stochastic, it is necessary to determine the reorder points, or equivalently safety stocks. To do this we first of all need a suitable demand model during the lead time (Axsäter, 2006).

According to the adjusted continuous review policy, when the inventory position drops to or below the reorder point R , an economic order quantity of Q^* is ordered to replenish the inventory in the car of technician, with a small adjustment, since the purchase orders may only be placed once a week, in the established day with the single supplier. We determine Q^* according to the basic EOQ formula (1.2), as it is a satisfactory approximation in case of stochastic demand (Axsäter, 1996; Ballou, 2004).

$$Q_w = \sqrt{\frac{2 \cdot F_0 \cdot \bar{d}}{F_1 \cdot c}} \quad (1.2)$$

The demand during the lead time (x) is a discrete stochastic variable and is derived from the total number of spare parts demanded by a set of the customers located in a given geographical area which is managed by the maintenance technician. According to the historical data, the demand during the lead time (x) has a Poisson distribution with average (D) score estimated on the mean of weekly de-

mand. Effectively, the weekly demand for each spare part is very low, sporadic and unpredictable.

The reorder point R is determined according to the service level, defined in the previous section. Thus, there is a specified probability (service level) for the demand during the lead time to be lower than R , *i.e.*, $P(x \leq R)$. The reorder point is derived from the reverse of the cumulative Poisson distribution function and the safety stock is equal to $R - D$.

2.5 Evaluation of the Proposed Inventory Management Policy

The proposed inventory management policy was applied to three spare parts from the AAV group, managed by a given technician, as these spare parts involve high criticality, high quantity and value of usage to calculate the total relevant inventory management costs as described in (1.1). These results are compared with the costs obtained from the traditional method used by the technician to manage those spare parts. Table 2 shows that the proposed policy is the most economic option in terms of ordering cost, stock out cost and total inventory management costs, fulfilling the service level contracted with the customer.

The traditional method is effectively more economic regarding the holding costs but the ordering costs and stock out cost are clearly higher than in the proposed policy. Also the service level is never fulfilled in the three spare parts.

Based on the results achieved, a decrease of the total inventory management costs is expected for all spare parts, as well as a significant increase in the service level for the global spare parts list.

Table 2 Total costs regarding the traditional and the proposed inventory policies

Item	Cost (€)	Traditional method	Proposed method
1	Acquisition	423	395
	Stock out	122	-
	Ordering	112	32
	Holding	17	50
	Total	673	476
2	Acquisition	1 427	1 522
	Stock out	61	-
	Ordering	207	64
	Holding	56	122
	Total	1 752	1 708
3	Acquisition	322	354
	Stock out	182	61
	Ordering	176	48
	Holding	6	40
	Total	686	503
Total of three items		3 111	2 688

3 Conclusion

The combination of the cross ABC and criticality analysis allowed to implement an inventory management policy never before used in the maintenance department through the definition of different inventory management policies and the establishment of service levels according to the spare parts criticality, the value and quantity of usage.

By implementation the proposed continuous review policy, the three AAV group spare parts present a higher service level than in the traditional method, as well as a reduction of 14% in the inventory management total costs due to the decrease in the ordering and stock out costs. The spare parts from groups with medium and low quantity of usage should be managed through the implementation of a Kanban system which is essential to control and maintain the inventory of these spare parts at the optimum level. With the proposed inventory management policies, improvements in the current service level and a reduction of the global inventory management costs are expected, in compliance with the strategic objective to fulfil the customer service level of the maintenance provider which decided to implement it in the near future.

For future developments, the gradual integration of each technician in the implementation of the proposed inventory management policy was suggested. This implementation should be monitored by calculating the inventory management total costs and real service level.

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