A heuristic to minimize the Inventory Value of Repairable Parts with Service Constraints: Application to an Airline Company

Cardós M[1], Babiloni E, Palmer M, Guijarro E

Abstract This paper focuses on the improvement of the inventory management of repairable parts of the airline company Air Nostrum. The company uses the sales replacement policy to manage their repairable parts and the same target fill rate is required for every item in order to assure a high availability of the aircrafts, dealing to a high inventory value. However, this paper shows that an alternative heuristic approach outperforms that approach in terms of inventory value while fulfilling the target fill rate that has been set for repairable parts. This improvement is illustrated with an extensive and real dataset.

Keywords: inventory management, airline industry, ABC classification

1.1 Introduction and literature review

Repairable parts are a kind of spare part that may be repaired and eventually used again. Nowadays the optimization of the inventory of repairable parts has become a strategic issue in industries such as airlines because: (i) they serve an installation with a high turn off cost; (ii) items are so critical that when just one of them is out of service then the airplane must stay on ground, also called aircraft on ground (AOG) condition; (iii) a high inventory level is needed in order to assure a high availability of the installation served; (iv) repairable parts are usually expensive and therefore repairing them becomes a good option to save costs; and (v) the resulting inventory value is usually very large, in fact it is told in this industry that one of every twenty aircrafts is always on the ground in the form of spare parts. Not surprisingly for the last years researchers have focused on developing models to improve the management of these items. A complete literature review on the subject can be found in (Guide and Srivastava 1997) and (Kennedy et al. 2002).

[1] Manuel Cardós Carboneras (✉)

Departamento de Organización de Empresas, Camino de Vera s/n, 46022 Valencia, Spain
e-mail: mcardos@omp.upv.es

In practice, the most common policy used to manage repairable parts is the base stock sales replacement policy (S-1, S). Additionally, most of the repairable items show erratic or lumpy demand, being zero demand the most frequent demand per period. Therefore, traditional approximations fail to provide acceptable fill rate estimations and as a consequence exact procedures are needed. In this context (Feeney and Sherbrooke 1966) develop an exact method to compute the fill rate as the expected amount of demand that can be filled immediately from the on-hand stock, assuming compound Poisson distributed demands. Some years later, (Muckstadt and Thomas 1980) apply that approach for Poisson distributed demands deriving the easy-to-compute expression to calculate the fill rate:

$$\beta_{M\&T} = F_L(S-1) \tag{1.1}$$

where S is the base stock level and $F_L(\cdot)$ is the cumulative distribution function of demand during the reparation lead time L. More recently (Palmer et al. 2010) propose a general expression to compute the fill rate for any discrete, independent and identically distributed demand:

$$\beta^* = \sum_{i=1}^{S} f_L(S-i) \cdot \left(\frac{F_I(i) - F_I(0)}{1 - F_I(0)} + \sum_{j=i+1}^{\infty} \frac{i}{j} \cdot \frac{f_I(j)}{1 - F_I(0)} \right) \tag{1.2}$$

If a company decides to use the fill rate as service level metric and the same target for all the items, then the reference stock will be one unit for most of the items due to the erratic nature of their demand, as will be explained later. Furthermore, the average expected fill rate will clearly exceed the target dealing to an unnecessary overstock. It should be noted that the average fill rate can be calculated (Thonemann et al. 2002) as the average of the item fill rates weighted by the fraction of demand corresponding to each item.

The company may go further and can set fixed service targets per ABC classes, using a demand value or demand volume criterion (Silver et al. 1998). However, the question is what those targets should be. The literature does not help because on the one hand some authors (Armstrong 1985) affirm that A items should have the highest targets to avoid frequent backlogs but on the other hand it has been argued (Knod and Schomberger 2001) that C items should have the highest service targets to avoid dealing with frequent stockouts.

Additionally (Zhang et al. 2001) have proposed a new ranking criteria according to the ratio $D/(L\,c^2)$ being D the expected annual demand, L the lead time and c the unit cost.

More recently (Teunter et al. 2010) have considered the classification from an inventory costs perspective and have proposed a cost criterion rank $(D\,b)/(Q\,h)$ being b the shortage cost, h the unit holding cost and Q the order size. This criterion includes a measure of item criticality, a factor considered by some authors es-

pecially for spare parts management, in the form of stockout cost. The authors claim that this criterion outperforms the previous ones.

However, it cannot be forgotten that: "Since a subjective evaluation of stockout cost is necessary in many (if not most) inventory-planning situations, the issue is not whether to make such an evaluation but how to make the evaluation" (Badinelli 1986). Therefore it has been suggested (Fogarty et al. 1991) that stockout costs should be replaced by an appropriate target service level. In fact, in practice it is not possible to provide an objective evaluation of stockout costs for an airline company.

Anyway, operations management have always to cope not only with the economical aspects of its decisions but also with their impact on the financial needs of the company. Accordingly the inventory cost optimization has received a lot of work, but surprisingly it has not happened to the inventory value optimization. This paper focuses on this gap so that the main objective of this paper is to provide a procedure to minimize the inventory value while fulfilling a target fill rate.

The remainder of this paper is organized as follows. In Section 2 we present the problem addressed by this paper. In Section 3 we propose the new heuristic to minimize the inventory value while fulfilling the average target fill rate and we examine some results base on an extensive historical dataset. Finally in Section 4 we provide our conclusion, some managerial insights and direction for further research.

1.2 Description of the problem

The Spanish airline company Air Nostrum is one of the most important European regional airlines, and is ranked among the 15 largest regional airlines in the world. This company operates 450 flights and more than 150 routes to over 60 destinations in European and African countries. The company has been involved in a project to improve the management of repairable and critical items because of their large inventory value and high impact on the customer service. Additionally, these parts cannot be easily replaced by a similar one due to international regulations.

Fortunately every item can be accepted to be equally critical because the lack of any of them may produce an AOG condition, so the consideration of the criticality of every part can be avoided.

The data used in this paper include are the historical data on failures that took place during 911 consecutive days for 941 items. In order to illustrate the behaviour of the failures, it is shown the histograms of SKU-1 and SKU-2 in Figure 1.1 and Figure 1.2 respectively. SKU-1 is one of the few spare parts having demand (failures) almost all the days while the demand of SKU-2 is zero except for one day with 7 units demanded and another one with 13 units. A chi-square test shows that both demand patterns can be described by a negative binomial but not by a

Poisson distribution. Having no demand during most of the periods is very usual for spare parts.
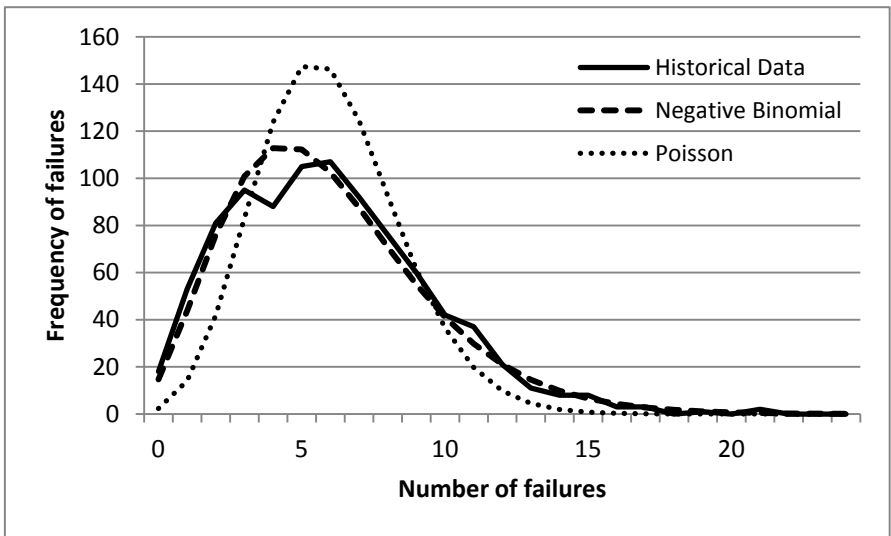

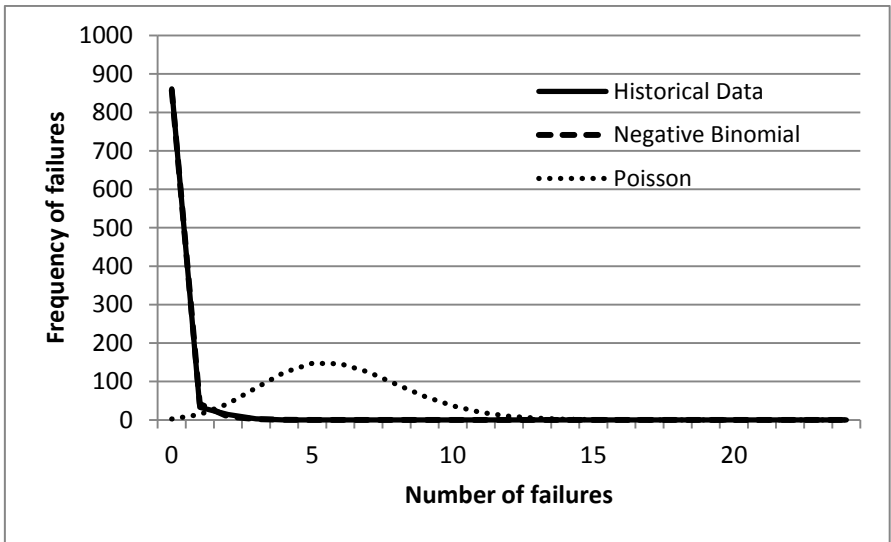**Fig. 1.1** Demand pattern of SKU-1

Fig. 1.2 Demand pattern of SKU-2

Statistical analysis shows that the demand pattern of these items can be described by a Poisson or a negative binomial distribution. However, these distributions play very different roles as shown in Table 1.1 where items have classified using an ABC demand volume criterion. About 80% of the item demand patterns

can be described by a Poisson distribution, but they only account for 28% of the units demanded. This justifies the need of expression (1.2) for the exact fill rate estimation.

Table 1.1 Distribution functions of demand patterns

Category	Poisson # parts	Poisson units	Negative binomial # parts	Negative binomial units
A	36	3,244	56	15,997
B	182	2,322	93	1,263
C	531	1,060	43	154
Total	749 (80%)	6,626 (28%)	192 (20%)	17,414 (72%)

It can be seen in Table 1.1 that class C items have an average demand as low as one unit per year or lower, so a dilemma appears. If a unit stock reference is set then the expected service level is about 100% but if no stock reference is set then the expected service level is 0%. This is an example of the kind of decisions involved in a multi-item stock reference assignment.

The problem we address can be formulated as the selection of a reference stock for every item so that the inventory value minimizes and the target average fill rate is reached. It should be highlighted that the solution to this problem includes the decision of which items should be stocked or not.

1.3 Proposed Heuristic and an Application

The heuristic we propose is based on a very simple idea: the next unit will be added to the item reference stock with the highest contribution to the average fill rate increase when compared to the inventory value increase. In order to apply this idea, the fill rate cost index (FCI) is defined for every item as:

$$FCI = \frac{w \times \{FR(S+1) - FR(S)\}}{c} \qquad (1.3)$$

being w the weight of the demand of the item, c the unit cost and $FR(S)$ the fill rate with an S base stock. In every step, an additional unit is increased to the most suitable item.

This approach is very easy to understand but quite complex to apply because every item has to be considered for every additional stock base unit. Alternatively a more efficient procedure can be applied to avoid the simultaneous evaluation of all the items:

1. A minimum FCI limit is set for all the items. In other words, it is established the lowest average fill rate increase that can be accepted per each Euro devoted to the inventory value.
2. In an item per item basis, it is determined the maximum stock reference exceeding the FCI limit.
3. If the average target fill rate is reached then the procedure stops, else step 2 is repeated and the FCI limit adjusted.

This procedure has been applied to the historical dataset of failures in Airnostrum beginning with a 1% increase of the average fill rate per each Euro added to the inventory value (FCI=0.01). The result is an average fill rate of 80% and 10.1 million Euros inventory value. Afterwards the FCI is lowered three times providing the data shown in Table 1.2 and illustrated in Figure 1.3.

Table 1.2 Minimum fill rate cost index (FCI), corresponding inventory value and average fill rate

FCI limit	Inventory Value (€)	Average Fill Rate
0.01000	10,066,670	0.80877
0.00100	14,871,837	0.92765
0.00050	18,878,887	0.95587
0.00030	23,660,378	0.97504
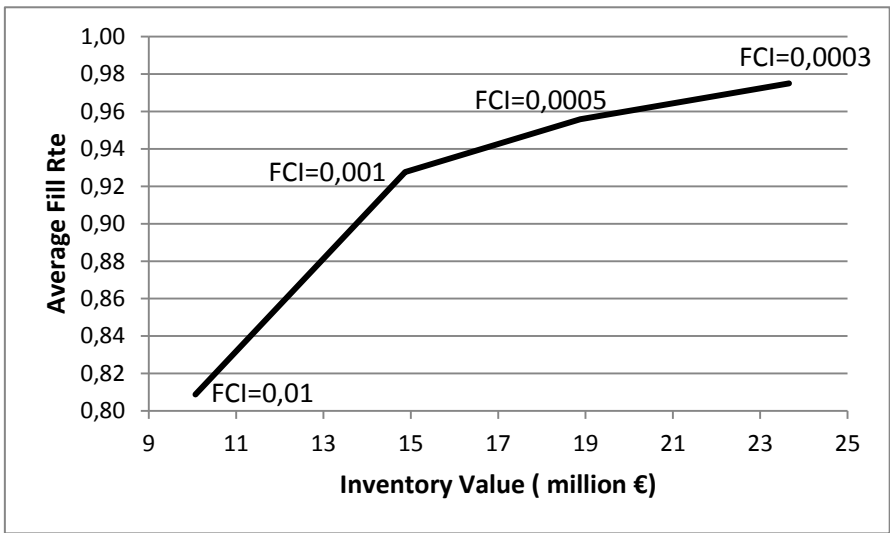
Fig. 1.3 Average fill rate vs. inventory value for different FCI values

It can be observed that the inventory value grows quicker than the service level. For example, 5 million Euros are needed to increase the average fill rate 12 points from 81% to 93%, but an additional investment of 4 million Euros is needed just

to increase another 3 points to 0.96. However, the most important point to be high-lighted is the company has reached a 97% average fill rate with 28.3 million Euros, so this heuristic reaches the same service level but lowering the inventory value in 4.6 million Euros.

1.4 Conclusions

A simple but effective heuristic has been proposed in this paper to reduce the inventory value subject to an average fill rate constraint in a multi-item context. This approach is not based on the usual ABC classification nor the more recent inventory cost perspective but on a novel inventory value focus. Additionally this heuristic does not require any subjective estimation such as in the case of the stockout cost.

Obviously these results have to be carefully evaluated before its implementation, including an extensive inventory cost assessment. Anyway, this method provides a lower bound of the inventory value reduction that can be obtained and can be very useful to reduce the financial stress that companies may suffer.

In a near future it should be analyzed the trade-off between inventory costs and inventory value optimization as long as both of them are connected to important aspects of the operations management.

1.5 References

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