A criticality-driven methodology for the selection of spare parts stock management policies: the case of a beverage industry company

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Abstract: Despite the huge number of scientific papers concerning the spare parts management, the traditional gap between theory and industrial practice remains still today unfilled. The purpose of the paper is to design and to develop an integrated methodology for spare parts management which, starting from a proposed classification method, provides the selection of the most suitable stock management policy, taking into account the criticality profile of each item. The methodology has been tested in an important Italian factory working in the beverage industry, showing encouraging outcomes in terms of effective applicability to a real industry. The methodology can be used by the maintenance material planner as a tool to classify spare parts and to choose the inventory control models basing on the peculiarities of spare parts; further on, it represents a tangible effort of bridging the gap between research and practice in the spare parts management.

Keywords: Spare Parts, Integrated management process, Inventory control, Analytic Hierarchy Process

1. Introduction

For many organizations, spare parts inventories consume a significant portion of their capital investment. This situation makes the management of these items a very critical issue that is worthy of careful study. In many organizations in the manufacturing, services and defense sectors, there are opportunities for cost savings by engaging in more efficient management of spare parts inventories, and the trend is that it is likely to become even more critical in the future. The key challenge is to maintain high spare part availability with low cost (due to inventory holding, warehousing, transportation, technicians, overhead, etc.) (Diaz & Fu, 1997). To this end, keeping a certain amount of spare part inventories balanced with their demand is required. Indeed, different inventory control practices are needed for two fundamental types of maintenance, i.e. scheduled or preventive maintenance, and unplanned repair. For scheduled maintenance, the demand for spare parts is predictable and it may be possible to order parts to arrive just in time for use, and it may not be necessary to stock spare parts at all. For unplanned repair, the consequences of stock-outs often cause interruptions in operations, some kind of safety stock is then needed.

Moreover, spare parts inventories used for maintenance operations differ from other manufacturing inventories in several ways. For example, rather than customer usage, maintenance policies dictate the need for spare parts inventories; and high variety of characteristics among spare items is normally observed within a warehouse (due to rates of consumption, purchasing costs, procurement lead times, etc.) (Braglia et al., 2004, Roda et al. 2014). Overall, the stochastic nature and the large number of distinct demanded parts add to the complexity of the planning process. This motivates the need for systemic actions while managing spare parts: the use of an integrated view is promising for the overall effectiveness of spare parts management in industrial companies. Nonetheless, as a matter of fact, integrating parts classification, demand management/forecasting, stock control models and performance measurement is still hardly present in literature (Bacchetti & Saccani, 2011).

The objective of this paper is to propose a methodology to support an integrated approach for managing spare parts, by allowing the matching of the most proper stock management policy to each spare item according to its criticality profile. A similar approach is in fact absent in the literature and few are the articles which analyze the stock policies and their applicability taking into account the peculiarities of spare parts. Starting from the analysis of the state of the art about classification and inventory control models for spare parts in Section 2, the proposed methodology for matching these two relevant steps of the management process is presented in Section 3. Section 4 is dedicated to the case study developed, within an important Italian factory in the beverage industry, in order to test the methodology. Each methodology's step is described, and the results from the application of two different algorithms at the matching step are compared. Conclusions are finally depicted in Section 5.

2. State of the art

2.1. Classification Models

Classification of inventory items is a crucial element in the operations of any production company (Björnfot & Torjussen, 2012). Because of the huge number of inventory items in many companies, great attention is directed to inventory classification, which consequently require the application of different management tools and policies.

In the literature, the classification models proposed over the years have evolved, starting from single criterion to multi-criteria classification models, based on different techniques. Once demonstrated that only one criterion does not allow an efficient decision-making process, multi-criteria methods have resulted largely preferred (Flores et al., 1995). As a consequence, a huge number of studies have been done on multi-criteria inventory classification and many different models for classifying spare parts have been developed in the last 25 years. According to the recent reviews, they can be categorized in quantitative and qualitative methods.

Classifications models based on techniques such as Linear Optimization Methods (Ramanathan, 2006, Zhou & Fan, 2007, Ng, 2007), Analytical Hierarchy Processes (AHP), Fuzzy Sets and AHP (FAHP) (Rezaei & Dowlatshahi, 2010, Chu et al., 2008) and Artificial Neural Networks (ANN) (Partovi & Anandarajan, 2002, Yu, 2011), belong to the first category. Among qualitative methods, the VED classification (Mukhopadhyay et al., 2003) is surely the most known; spare parts are classified as vital (V), essential (E) and desirable (D) items, based on consultation with maintenance experts.

Among the quantitative approaches, the AHP developed by Saaty (1988) has been successfully applied to multi-criteria inventory classification [Flores et al., 1992 Gajpal & Ganesh, 1994). The advantage of AHP is that it can incorporate many criteria and is easy to use on a massive accounting and measurement system; its shortcoming is that a significant subjectivity is involved in pairwise comparisons of criteria. AHP was utilized to reduce multiple criteria to a univariate and consistent measure. The reader could review Roda et al. (2014) for an updated description of classification models proposed in the literature.

2.1.1. Classification Criteria Analysis

The multi-criteria classification models require as input a set of criteria for a proper analysis of criticality. In the literature, excluding some exceptions (Braglia et al., 2004, Roda et al. 2012), there are no papers with an exhaustive overview of the criteria to be used for an effective spare parts classification. Most of the works propose multi-criteria classification models but none of them foresees the use of a set of globally accepted criteria. In order to overcome this limitation the criteria adopted in the 20 most cited articles has been selected and reported in a frequency histogram (Figure 1).

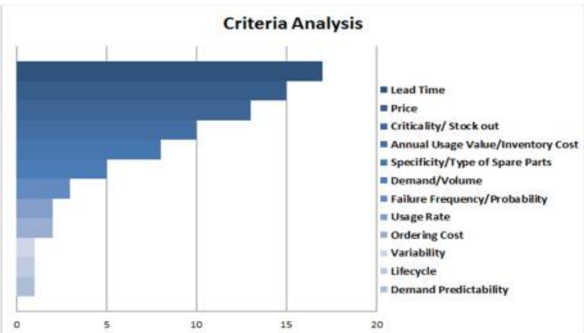

Figure 1: most adopted classification criteria in the literature

As can be seen from the graph, the analysis of literature does not allow to define an optimal set of criteria for a proper classification of spare parts, because most of them result mutually dependent and, moreover, some of them are difficult to obtain or measure in real contexts.

2.2. Inventory Control Models

The main questions which an inventory control model has to be able to answer to are: (i) which spare parts have to be stocked?; (ii) how many units have to be kept in stock for each of these spare parts? (iii) when do they have to be ordered and in which quantity?

Literature on the planning and operational level of spare parts in most cases has focused on the determination of their optimal inventory level (Huiskonen, 2011, Kennedy et al., 2001). Besides, theoretical models for slow-moving items are abundant (Huiskonen, 2011). The importance of spare part inventory planning has even increased, since the value of spare parts that an average manufacturing company holds on stock has soared in the last century. Subsequently, the variety of research in the management of maintenance inventory is very broad in scope, the literature includes some rather non-technical treatments that offer a systemic view of spares inventory management, as well as those that are more technical and narrow in nature. Moore (1996), which is an example of the less technical papers, suggests an approach to manage spares inventory based on reliability, capacity objectives and a systematic strategy; on the other hand, the more technical researches are generally concentrated on the mathematical resolution of inventory models, more than on the understanding of their field of applicability.

The review of the literature has allowed to select the 7 most used / cited spare parts inventory models:

(i) continuous review, with fixed reorder point *(s)* and fixed order quantity *(Q),* referred to as *(s, Q)*;
(ii) periodic review, with fixed ordering interval (R), with fixed re-order point (s) and fixed order quantity (Q) referred to as (R,s,Q)
(iii) periodic review, with fixed ordering interval *(R)* and order-up-to level *(S),* referred to as *(R,S)*;
(iv) continuous review, with re-order point *(s)* and order-up-to level *(S),* referred to as *(s,S)*;
(v) periodic review, with fixed ordering interval (R), with re-order point *(s)* and order-up-to level *(S),* referred to as *(R,s,S)*;
(vi) continuous review and order-up-to level *(S)* in a one-for-one replenishment mode, referred to as *(S-1,S)*.
(vii) continuous review, with re-order point (s) one or zero policy that resolves the main spare parts problem: stock or no stock.

Each stock policy can have different implementation of the control models according to the objective which can be: (a) inventory costs minimization, (b) service level maximization and (c) system availability maximization.

Despite the great number of studies on the matter, what can be generally noted is that the main lack of this wide research is an adequate vision about the real practical needs of the industrial environment (Bacchetti & Saccani, 2011). Such needs may indeed be answered by having on hands a "tool" to help managing the stock by identifying proper models to be used for different kinds of spare parts. But, as noted in (Wagner & Lindemann, 2008), some researches that have investigated inventory concepts in manufacturing companies revealed a great discrepancy between theory and application. Hence, such a "tool" is not available. In particular, the required integration between spare part classification and stock management policy selection has been not sufficiently deepened because the logic which should connect the two phases results still fragmentary and is too often committed to the planner experience.

3. Proposed methodology

The purpose of the paper is to design and to develop an integrated methodology for the automatic matching of the most suitable stock policy to each spare part taking into account its criticality. More precisely, starting from some studies (Roda et al., 2012, Bacchetti & Saccani, 2011, Cavalieri et al., 2008) in which five sequential phases to manage spare parts were defined, this work proposes to integrate the process of spare parts classification with the process of stock management policy selection taking into account the criticality. Figure 2 shows the general framework of the methodology.

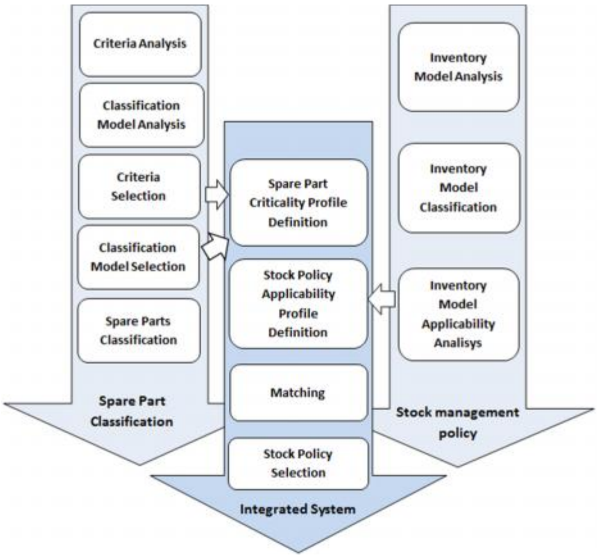

Figure 2: the methodology framework

The integrated system exploits the criteria selected for the spare parts classification and uses them, weighted through an AHP analysis, to define the *criticality profiles* of spare parts: such profiles are used to express not only the criticality – which is obvious – but also to synthetically characterize the peculiarities of each spare part (high lead time, mid purchasing cost, etc.). The same criteria and relative weights are also utilized to define the *applicability profile* for each stock management policy selected from the literature: all the applicability profiles are summarized in a matrix called, in the reminder, SPA (Stock Policy Applicability).

The association between the spare part classification and the stock policy is then possible thanks to a matching step in which the *criticality profile* of the spare parts is compared with the *applicability profiles* of the stock policies. The profiles can be automatically compared and associated to assign the most proper stock management policy to each part, through two alternative algorithms: SWD (Weighted Shortest Distance) and RSM (Recursive Selection Method).

The SWD algorithm was developed with the objective of minimizing the total weighted distance between the criticality profile of the spare part and the applicability profiles of the stock policies. The distance is calculated as the difference between the levels assigned to the spare part and to the stock policy for each criterion of part classification, while the weight is given by the AHP analysis to that criterion. The total distance is the sum of the distances calculated for all the classification criteria.

The RSM algorithm compares the criticality profile of the spare part with the applicability profiles of stock policies: the applicability profile which coincides exactly with the criticality profile is then associated. In the case in which there is no policy with the same profile of the part, the algorithm starts to compare partitions of the two profiles by excluding from the analysis a criterion. If matching is negative for all partitions with n-1 criteria, the algorithm begins to analyze partitions excluding two criteria from the analysis, etc..

Overall, the two matching algorithms, based on different logics, make the association of the most proper stock management policy to each spare part possible. The final result of the methodology is the selection of a mix of stock policies, each one associated to a set of spare parts, according to what suggested by the matching step.

4. Case study

The methodology has been implemented in the warehouse of the Crodo plant of the Campari S.p.A., a large Italian company operating in the beverage sector. To develop this case study, the following steps were followed: (i) Criteria selection (ii) AHP Analysis and definition of criticality profiles, (iii) SPA matrix definition for stock policies, (iv) Matching between spare part criticality profiles and stock management policy applicability profiles, (v) Stock policy selection.

4.1. Criteria selection

The classification criteria have been selected taking into consideration which are the most used / cited ones in the literature, as evidenced in Figure 1, their respective calculation methods, and the data obtainable from the ERP SAP of the Campari Plant. The result of this selection is shown in Figure 3.

According to it, the adopted criteria are: Lead Time, Stock out, Price, Specificity and Failure Frequency. Table 1 describes the calculation modes of those criteria.

Particular attention has been given to the Stock out cost parameter. Many authors state that it is the most difficult criterion to calculate with a quantitative formula because in practice there is an absence of data necessary to calculate it. Huiskonen (2011) states that in practice, due to the absence of the necessary data, the Stock-out can be calculated as a downtime cost. Celebi (2008) argues that this criterion, in absence of quantitative data, should be calculated in a qualitative way by defining a scale and associating for each spare part a degree of criticality through expert judgments. Such solution was adopted in the case.

The Failure Frequency was selected because the demand for spare parts is made up of a regular and an irregular part. The regular part is due to all those consumption resulting from planned interventions that can be normally operated even not keeping spare parts in stock but buying them a lead time before their utilization. The irregular part instead is generated from all consumption caused by failure interventions and it's therefore difficult to predict; it cannot be managed without taking stocks in warehouse. Given the irregularities due to failures, the failure frequency plays a crucial role in the critical analysis of a spare part (Bacchetti & Saccani, 2011).

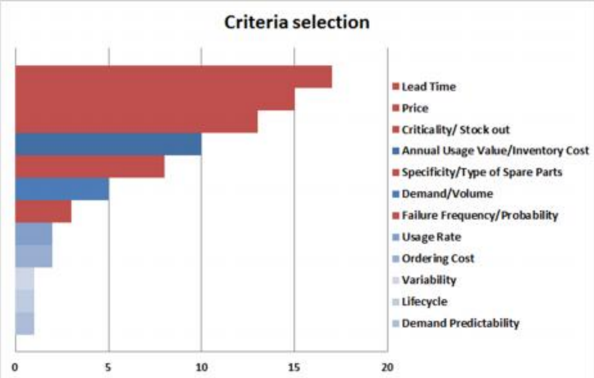

Figure 3: classification criteria adopted in Campari S.p.A.

Table 1: Calculation modes of the adopted criteria

Criterion	Description of the calculation mode
Specificity	Using the material master data of the part and of its suppliers in SAP, it is possible to determine whether a spare parts is standard or non-standard and if it is supplied from a local or overseas supplier.
Price	It is calculated as the average purchase price by analyzing the Purchase Orders in the period 2010-2013.
Failure Frequency	It is calculated through the analysis of all the work orders (Type Breakdown) in the period 2010-2013 requiring the replacement of the part.
Stock out Cost	Given the difficulty of a quantitative calculation, to each part a qualitative degree of criticality is associated: H (High), M (Medium) L (Low) and R (Very low).
Lead Time	It is calculated as the average time that elapses from Purchasing Request issued by the Maintenance Department and the inbound delivery of the part in the warehouse.

4.2. AHP analysis and definition of criticality profile of spare part

The AHP analysis was applied to the 5 chosen criteria. Thanks to the expert judgment a weight has been associated to each criteria (C1,..,C5) and to each mode (M1,…, M4), as reported in Figure 4.

By calculating the product of the weight of the criteria and the relative weight of the mode, it is possible to obtain the five points defining the criticality profile of each part. The following formula shows how to calculate them:

$$CProfile_i = [C_1 M_{i,1}, C_2 M_{i,2}, C_3 M_{i,3}, C_4 M_{i,4}, C_5 M_{i,5}] \quad (1)$$

where:

C_1, C_2, C_3, C_4, C_5 are the criteria weights

$M_{i,1}, M_{i,2}, M_{i,3}, M_{i,4}, M_{i,5}$ are the mode weights assumed by the i-th part.

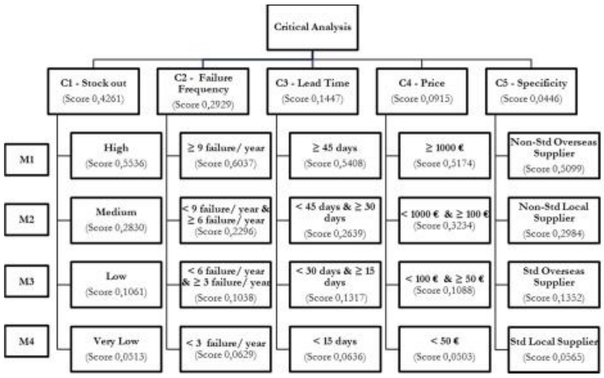

Figure 4: AHP analysis for spare part profiles definition

Below an example of criticality profile creation is reported. The part No. 804156 has high criticality about stock out (M1) and is a non-standard component with overseas supplier (M1); its purchasing cost is about 300€ (M2) and has manifested a frequency of failure of 2 events per year (M4); its average lead time is about 16 days (M3). The relative criticality profile is reported in Figure 5.

Spare part	Description	C1	C2	C3	C4	C5
		0,4261	0,2929	0,1447	0,0915	0,0446
804156	ALBERO CFG	M1	M4	M3	M2	M1
		0,5536	0,0629	0,1317	0,3234	0,5099

$CProfile_i = [0.2359, \ 0.0184, \ 0.0191, \ 0.0296, \ 0.0227]$

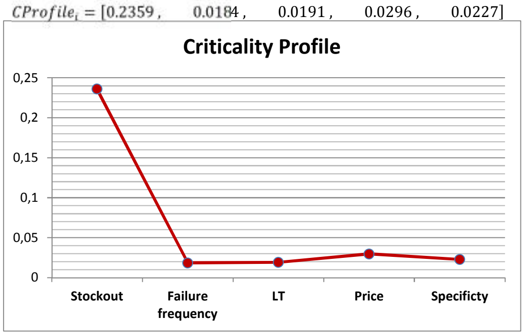

Figure 5: Criticality profile of spare part no. 804156

4.3. Stock Policy Applicability Matrix and Applicability profile definition

The definition of the Applicability profile is one of the main results of this work because the literature in which the applicability of the inventory models in terms of spare parts peculiarities is very scarce. The SPA matrix has been designed and developed using the few articles presented (Roda et al., 2012, Roda et al. 2014) and the logical deductive reasoning. Particular attention has been given to the Failure Frequency. In the literature there is an explicit link between management stock policies and the Failure frequency. So, given that "*the failure intervals correspond in inventory language to the demand intervals and the demand sizes to the number of failed parts*" (Saidane et al., 2011), it is possible to deduce that in the language of the warehouse the frequency of demand may be connected to the frequency of failure. This assumption has linked the Failure frequency to the concept of fast, normal and slow moving items, which is a concept widely studied in the literature with particular attention to the connection with the applicability of the stock policies. Table 2 shows the SPA matrix obtained with the analysis; it reports, for each stock policy, the levels of the criteria which fit better with it.

Table 2: SPA matrix

	Stock Out	Failure Frequency	Lead Time	Price	Specificity
(s,Q)_a	Med/low	High/med	Med/long	High	Med/low/ very low
(s,Q)_b	Unknown/low /very low	High/med	Med/long	High	Med
(R,s,Q)_a	Med/low	Med/low	Med/long	Med/low	Med/low/ very low
(R,s,Q)_b	Unknown/low /very low	Med/low	Med/long	Med/low	Med
(R,s,Q)_c	High	Low	Very Long	High/med	High/med
(R,S)_a	Low	Med/low	Med/shor t	Low	High/med
(s,S)_a	High/med	Low/Very low	Short	High	High/med
(R,s,S)_a	High/med	Low/Very low	Med/log	Med/low	High/med
(R,s,S)_b	Unknown/low /very low	Low/Very low	Med/long	Med/low	High
(S-1,S)	Unknown/low /very low	Low/Very low	Med/long	High	High/med
One or Zero	Low/very low	Very Low	Short	Very high	Low/ very low

Basing on the SPA matrix, and converting its qualitative judgments in the 4 weighted modes according to the previously carried out AHP analysis, the Applicability profiles of the stock policies were built, using the same formula as the spare part criticality profile. The results are displayed in Figure 6.

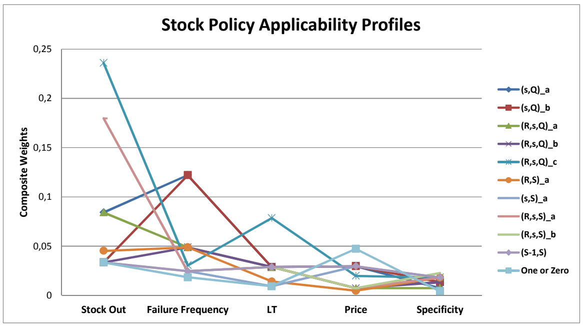

Figure 6: Applicability profiles of stock control policies

4.4. Matching and policy selection

The methodology has been applied to all the 1200 spare parts in the warehouse of the Campari plant. The association of the correct stock management policy to each spare part was possible through the implementation of the two algorithms, RSM and SWD, as described before. The results are summarized in Figure 7, in which the spare parts are also divided into 4 classes of importance (Vital, Essential, Important and Desirable), according to what proposed by Sharaf & Helmy (2001), as a variant of the original VED method.

Independently from the chosen algorithm, the result is that there is a very weak relation between chosen policy and class of spare part. This confirms that the criticality profile of the spare part, better than its criticality class, can enable assigning a proper stock management policy.

Quite all the stock policies have items assigned to them from both the algorithms, which means that there are not redundancies in the proposed set of alternatives. In spite of that, some policies appear to be more preferred than the others. In particular the most chosen is the One or Zero Strategy with the 30-38% of the items, mainly in Important and Desirable classes. (S,s)_a (mainly for Vital and Essential parts), (R,s)_a and (R,s,S)_b (both essentially for Important and Desirable classes) are also often preferred with more than 12% of items assigned to each one of them.

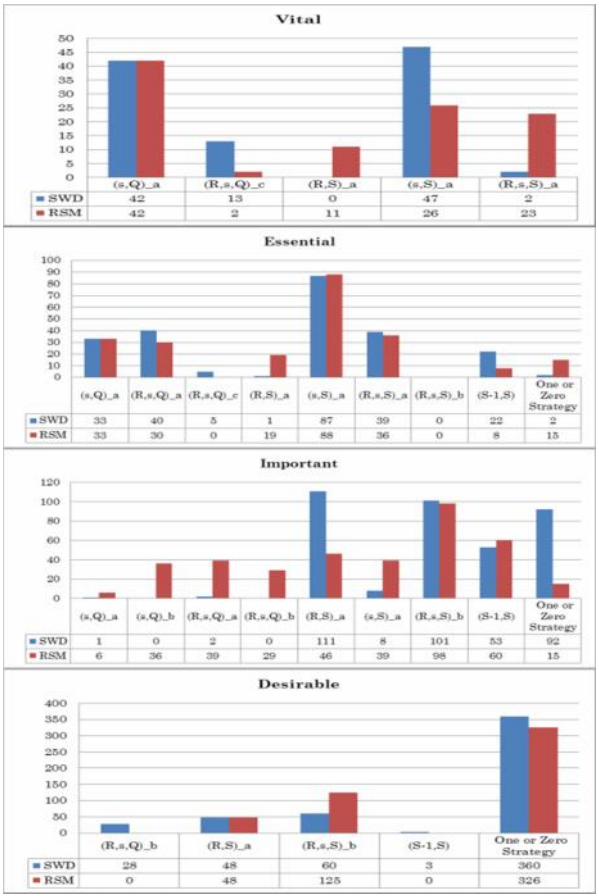

Figure 7: Stock policy assignment results

As regards the example of spare part No. 804156 (see Figure 5) which belongs to the class of Vital items, the result of the assignment done by the SWD algorithm is the (s,S)_a policy. Figure 8 shows the matching of the two profiles, evidencing their good fitting.

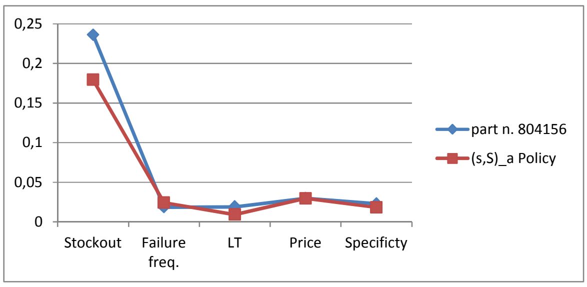

Figure 8: Matching between spare part N.804156 and (s,S)_a policy

5. Conclusions

This paper aims to overcome some shortcomings of the literature, relative to the allocation of the correct stock management policy to spare parts taking into account their peculiarities, hence their criticality. In particular, the

literature is full of proposed inventory control models, but all of them seem to be presented without a clear connection with the characteristics of the spare parts to which they have to be applied to. Along with this aspect, the need to distinguish among different spare parts, to get to a differentiated control of them, has emerged in order to get to a more efficient management system.
The definition of the integrated framework and its contextual application to an industrial case study has allowed building it without losing the focus on the practical dimension and, on the other hand, has allowed validating it in the industry word by identifying needs and application limits of models presented in literature to real companies' contexts.

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