A comparison of multi-criteria methods for spare parts classification

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Abstract

Spare parts classification is a fundamental step in spare parts inventory management. Through classification, the parts are grouped using a set of relevant criteria. Methodologies and methods for multi-criteria decision making are used to support the classification of spare parts. In this paper, a comparative study between the use of the multi-criteria classification based on rules and the multi-criteria classification using the Analytic Hierarchy Process is presented, showing the advantages and disadvantages of each method. The study confirmed that the multi-criteria method based on rules is more easily applied in organizations. The multi-criteria method using Analytic Hierarchy Process required more calculations, turning the implementation of the method more complicated, especially for non-Analytic Hierarchy Process specialists.

Keywords: Spare parts management; multi-criteria classification; Analytic Hierarchy Process.

Introduction

The role of the Multi-Criteria Decision Analysis (MCDA) or Multi-Criteria Decision Making (MCDM) in different application areas has increased significantly, especially as new methods arise and as known methods are improved (Velasquez and Hester, 2013). This area can also be referred to as multi-criteria decision aid, since it focuses on aiding decision making when multiple criteria are taken into account. Thus, the purpose of multi-criteria decision aiding is to present a variety of methods and methodologies that can help decision-makers to assess a finite set of defined alternatives, considering two or more criteria (Zopounidis and Doumpos, 2002). This approach consists of analyzing a limited set of options, among which a decision-maker has to select one or classify all, considering a set of criteria weighted according to their importance. For each alternative, an evaluation is made for each criterion using a suitable measure. Subsequently, the evaluations are aggregated to obtain a global classification of each alternative (Shafiee, 2015).

Zavadskas, Turskis, and Kildiene (2014) mentioned that MCDM refers to making decisions in the presence of multiple, usually divergent, criteria. The past decades have seen an increase in all main areas of MCDM, such as:

- Formal methods (algorithms, procedures and selection paradigms);

- Evaluation theories (assumptions about values or predilections and structured representations of values or preferences);
- Evaluation methodologies (elicitation, estimation, and scaling of individuals' preferences).

MCDM helps in improving strategic planning, communication, and understanding natural resource management. These can be used to support interactive decision making in a decision support system (Ananda and Herath, 2009). The MCDM has broad applicability and supports decision making in several areas, such as medicine, pattern recognition, human resources management, production system management and technical diagnosis, marketing, environmental and energy management, ecology, financial management, and economics (Zopounidis and Doumpos, 2002). The productivity of an organization is strongly influenced by decision making in product support logistics areas, such as maintenance (Teixeira de Almeida, 2001). Spare parts availability is important for efficient maintenance repair processes. These are necessary to certify an economical machine operation (Tracht *et al.*, 2013). Spare part classification procedures involve several tangible and intangible objectives that often conflict. Therefore, MCDM is a useful approach to solving these problems (Jajimoggala, Rao and Beela, 2012).

Spare parts inventory management is primarily intended to help maintenance keep equipment in working order (Roda *et al.*, 2012). Classification is one of the critical issues to achieve an efficient inventory management. An important issue concerning parts management is that it usually has to consider a large number of different parts. Spare parts classification is therefore important to determine service requirements for different spare parts classes, for demand forecasting and stock control decisions (Bacchetti and Saccani, 2012). According to Dekker, Kleijn, and Rooij (1998), the classification of spare parts serves to highlight the most critical spare parts and which must be kept in stock to ensure production.

The main objective of this paper is to present a comparative study between the multi-criteria classification based on rules and the multi-criteria classification using Analytic Hierarchy Process (AHP), for the classification of spare parts. The multi-criteria classification based on rules was used by Teixeira, Lopes, and Figueiredo (2018) using data from an automotive company. The same data was used in the multi-criteria classification with AHP. The purpose is to identify the advantages and disadvantages of the two methods for the classification of spare parts.

The paper is organized as follows. In Section 2, a literature review on multi-criteria classification for spare parts management is presented. Section 3 presents the classification for spare parts management, using the two different methods, the rule-based multi-criteria classification, and the AHP classification. The practical implications, advantages and disadvantages of each method are discussed. In section 4, the main conclusions are presented.

Literature Review

Spare parts classification is an important step to guide the whole management process. Classification is essential to know which spare parts are most relevant and which should receive the most attention (Cavalieri et al., 2008; Syntetos, Boylan, and Disney, 2009). Spare parts classification allows us to identify the most important spare parts and then identify the best spare parts management strategies (Hu et al., 2018). By classifying parts, inventory management can be aligned with criticality and demand forecasting, and spare parts management can be carried out, looking at the various classes of spare parts. Therefore, performance improvement actions can be performed considering the most critical classes, thus facilitating spare parts management (Roda et al., 2014). Different methodologies based on MCDM are presented in the literature to analyze the classification of spare parts. This section is divided into two topics or subsections, namely, multi-criteria classification for spare parts management and the AHP. With the first subsection, it is intended to analyze the various methodologies used in classification for spare parts. The AHP subsection provides a more comprehensive explanation of the method.

Multi-criteria classification for spare parts management

In the literature, several studies are presented that show the applicability of multi-criteria classification methodologies and methods for inventory classification. The traditional ABC classification cannot include the various dimensions of spare parts management because it uses only one criterion. The use of multiple criteria in spare parts classification is most appropriate since it attempts to consider all management and control requirements of operations related to this type of item. To solve this problem, new approaches that consider multiple criteria are emerging in the literature (Hu *et al.*, 2017).

Flores and Whybark (1986, 1987) presented an ABC analysis approach where classification is possible through two criteria. The procedure is a cross-matrix methodology for implementing the two criteria approach. Flores, Olson, and Dorai (1992) presented a methodology that uses AHP to incorporate the various criteria. AHP generates a consistent measure that can be used for the reclassification of inventory items in a simple ABC analysis. When the reclassification process is made, a resource limitation variable can be used to create the new grouping. This approach has the limitation that adding criteria to the classification process takes longer due to the amount of information. Partovi and Burton (1993) propose a methodology that uses AHP to incorporate all quantitative and qualitative criteria relevant for spare parts classification. A set of simulation tests was performed to realize the benefits of the methodology. The results of this classification method showed that, on the one hand, there was a marginal increase in order costs, and, on the other hand, there was a substantial reduction in downtime and average investment.

The classification methodology proposed by Braglia, Grassi, and Montanari (2004), called Multi-Attribute Spare Tree Analysis (MASTA), aims to use criteria based on the criticality of spare parts. The methodology has two sequential steps: the first step proposes the identification of four spare parts classes using a logical tree. In the second step, the appropriate stock management strategies are defined for each of the four classes. The AHP method is used to support the decision on each node of the logical tree.

Subsequently, Cakir and Canbolat (2008) suggest the use of fuzzy AHP (FAHP) for multi-criteria inventory classification. This approach is supported using information technologies such as Java Servlets and MySql database. A research study by Çebi, Kahraman, and Bolat (2010) suggested the application of FAHP to classify inventory items considering various attributes. An advantage of this study is that there is a good acceptance by users of the organization where the study was conducted. Hadi-Vencheh and Mohamadghasemi (2011) presented a multi-criteria classification methodology that combines the FAHP with data DEA, entitled FAHP-DEA. It uses FAHP to determine the weight of the criteria, with language terms such as very high, high, medium, low, or very low, evaluating each item in each criterion. The DEA is used to determine the value of the linguistic terms and the additive weighting method to aggregate the scores of each item.

Kabir and Hasin (2012) suggest the FAHP methodology for multi-criteria inventory classification that is used to determine the relative weights of the criteria, by classifying inventories into different categories. The FAHP methodology is used to synthesize the opinions of decision-makers to identify the weight of the criterion. The methodology has the advantage of being able to include the inaccuracy of human thinking. Kabir and Hasin (2013) added to the FAHP methodology the use of artificial neural networks. The back-propagation learning algorithm has been used in the developed feed-forward single hidden layer network. The input and output vectors were supplied to the network, and it was a supervised learning scheme. The result shows that the methodology can be successfully implemented to classify items or inventories. The back-propagation neural networks were proved to be suitable for classifying items.

Lolli, Ishizaka, and Gamberini (2014) proposed a hybrid methodology that aggregated AHP with the K-Means (AHP-K) algorithm and was later also introduced in AHP-K-Veto. The AHP-K-Veto is used when judged necessary by the decision-maker, to prevent an item appraised as high/low on at minimum one criterion to be bottom/top-ranked, when aggregation is made on all criteria. The disadvantage of the veto system is that it worsens the clustering validity index since it contradicts the objective of the clustering methods. It is, therefore, important to choose a veto with caution and not to abuse it. The method proposed by Kolinska and Kolinski (2018) supports the management of spare parts using classification. The spare parts classification presented is divided into two parts: a classification based on spare parts frequency of use and on its criticality. Spare parts classification by frequency of use divided items into three classes based on their history of consumption. The second part of the classification is based on the criticality criterion, taking into consideration the knowledge and experience of maintenance department employees and using the AHP method. In a research study by Ayu Nariswari, Bamford and Dehe (2019), a multi-criteria inventory classification model using AHP for aircraft spare parts management was developed and tested. Two steps were used in spare part inventory management as follows: define the spare part criticality and define the inventory strategy.

In the methodology developed by Partovi and Anandarajan (2002), artificial neural networks for the ABC classification of spare parts are used. In artificial neural networks, two types of learning methods were used, the back-propagation algorithm and the genetic algorithms, which aim to know the classification capacity of artificial neural networks. This methodology replicates the manager's decision based on the criteria data for the classification of each spare part. An ABC-fuzzy classification is an approach that aims to deal with nominal or non-nominal variables, incorporating the manager's experience, knowledge, and judgment. The approach procedure is due in the following steps: project the criticality function (divided into very critical, critical and non-critical); rank all items based on ABC analysis; and using fuzzy classification to classify into three subgroups based on their criticality. This approach has been applied to spare parts sets (Chu, Liang and Liao, 2008). Ladhari, Babai, and Lajili (2016) proposed new procedures that may use different ABC classifications as input. The main objectives of this study were to develop a new hybrid model, based on the improve the Ng (2007) weighted linear program by incorporating the composite index concept of Zhou & Fan (2007) and to propose new general procedures that can be used as input for different ABC classifications, to reach as output a consensus between them.

In the research study by Molenaers *et al.* (2012), the multi-criteria classification method used appeals to the AHP and the logical tree, combining these two methods, the various attributes that influence the criticality of spare parts is looking at rationally. AHP is used to determine the overall alternative score that is desirable, essential, or vital, considering the combination of individual sub-criterion assessments. The logical tree is intended to select the user to the appropriate level of criticality for each spare part.

Another methodology for multi-criteria classification is a three-dimensional approach. In this case, two dimensions to estimate the value and predictability of spare parts using the ABC and XYZ analysis are applied. The third dimension is the application of VED to classify spare parts by criticality. AHP is used to solve decision problems with the various criteria at different nodes in the decision tree (Stoll *et al.*, 2015). The methodology carried out by Antosz and Ratnayake (2016) has as its primary objective the identification of crucial spare parts, in terms of maintenance and logistics. The proper purchase and spare parts maintenance process will help to reduce the costs related to buying and storing unnecessary parts. The fundamental advantage of this methodology is the identification of such spare parts. Hu *et al*. (2017) presented a three-phase multicriteria classification framework for spare parts management using the dominance-based rough set approach (DRSA). In phase 1, a set of decision rules is generated from historical data using the DRSA. In the second phase, the generated rules are validated using the automated approach, and a manual approach and cross-validation and feedback evaluations are performed. Finally, in phase 3, a set of spare parts in real context is classified.

Teixeira, Lopes, and Figueiredo (2018) presented a multi-criteria classification methodology combining maintenance and logistics perspectives that intends to distinguish and group spare parts, and then defines the most appropriate stock management policy for each group. This methodology is divided into two steps, and the first step consists of defining the criticality of spare parts. The criticality was identified using a double-entry matrix. The criticality is determined using two criteria, namely function, and production impact. In the second step criteria related to inventory management are added, namely, lead time and price.

Throughout the literature review, it was observed that AHP is a method widely used in the proposed methodologies. It was further observed that AHP was incorporated in some cases with other methods.

Analytic Hierarchy Process

AHP, developed by Saaty (1980), is used in a wide range of areas, especially operations management, to solve complex decision problems using alternative prioritization (Gass and Rapcsák, 2004; Subramanian and Ramanathan, 2012). This technique can be used when considering qualitative and quantitative factors and helps to define critical factors by establishing a hierarchical structure similar to a family tree (Bevilacqua and Braglia, 2000). In this case, the relevant data are obtained from the use of a pairwise comparison set. AHP uses a hierarchical structure of various levels of objectives, criteria, sub-criteria, and alternatives. These comparisons are used to define the weight of each criterion and the performance measures relative to the alternatives for each criterion. AHP implementation can be structured into 3 steps (Bevilacqua and Braglia, 2000):

1. Define decision criteria in the form of a hierarchy of objectives, and this means structured on different levels;

2. Weight the criteria, sub-criteria, and alternatives as a function of their importance for the corresponding element of the higher level;

3. After a judgment matrix has been developed, a priority vector to weight the elements of the matrix is calculated.

This method also checks the consistency of comparisons and provides a mechanism for improving comparisons where comparisons are not consistent (Triantaphyllou and Mann, 1995).

Classification for spare parts management

The multi-criteria classification of spare parts is critical for an efficient management. Selecting the criteria and the classification method to be used are significant steps. As such, this study intends to make a comparative analysis between the multi-criteria classification based on rules (Teixeira, Lopes and Figueiredo, 2018) and the multi-criteria classification using AHP. The same data was used to identify the advantages and disadvantages of each method.

Initially, the multi-criteria classification proposed by Teixeira, Lopes, and Figueiredo (2018) is presented. Then, a new classification is performed using AHP. In this case, the weights to be assigned to each criterion and Idealized Priority of each level are calculated. Finally, the advantages and disadvantages are presented for each method.

Multi-criteria classification based on rules

The multi-criteria classification based on rules proposed by Teixeira, Lopes, and Figueiredo (2018) aims to create groups to assign a stock management policy. As such, a set of criteria was selected, namely, criticality, lead time, and price. The result of criticality is presented at three levels: vital, essential, and desirable. In the case of price and lead time criteria, a study was performed to define the ranges of the three defined levels: low, medium, and high. Table 1 shows the criteria and levels.

Table 1: Criteria levels

Criteria/Levels	Criticality	Lead time	Price
High	Vital	> 15 days	> 1500 €
Medium	Essential	> 5 days and ≤ 15 days	> 300 € and ≤ 1500€
Low	Desirable	≤ 5 days	≤ 300 €

After selecting the criteria and levels, the authors defined the decision tree as the classification method. Fig 1 shows an excerpt from the decision tree to exemplify its structure.

The expert panel has set the order of importance of the levels, and the rule of levels is related to the values that are within each range.

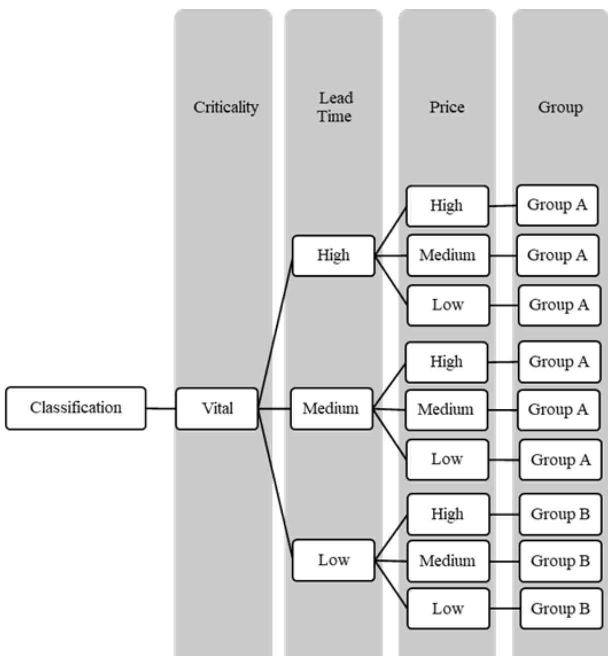

Fig 1. Decision tree for the classification

Multi-criteria classification using AHP

The definition of criteria weights will be made through comparisons between criteria considering the scale of relative importance proposed by Saaty (1980). In this case, the activities are the criteria, and the scale is used to compare the importance of each criterion to the ranking objective. The pairwise comparisons must be defined considering the expert opinion, and a matrix can be built with their values. The Consistency Ratio (CR) must be determined, and it has to be less than 10%.

The first step would be to choose the classification criteria, but in this case, the criteria presented in the Teixeira, Lopes, and Figueiredo (2018) study are used (Table 1). For each criterion, a weight was defined through pairwise comparisons using the scale of relative importance proposed by Saaty (1980). The pairwise comparisons were defined using expert opinion, and the values are presented in Table 2.

Table 2: Pairwise comparison matrix and determination of weight

	Criticality	Lead Time	Price	Weight
Criticality	1	5	9	0.75
Lead Time	1/5	1	3	0.18
Price	1/9	1/3	1	0.07

The consistency of these pairwise comparisons was analyzed, and the value of λmax is 3.03, Consistency Index (CI) is 0.01, and CR is 0.025 (2.5%). As the CR is less than 10%, the pairwise comparisons are consistent.

Each criterion was divided into three levels, as presented in Table 3. In this method, it was measured that pairwise comparisons of the levels inside each criterion are equal in every criterion. Each level was compared to other levels through pairwise comparisons as presented in Table 3. After calculating the weights, each weight was divided by the maximum weight to obtain the idealized priorities.

Table 3: Comparisons between levels and idealized priorities

	High	Medium	Low	Weight	Idealized Priority
High	1	5	7	0.74	1.00
Medium	0.20	1	2	0.17	0.23
Low	0.14	0.5	1	0.09	0.13

The consistency of these pairwise comparisons was analyzed, and the value of λmax is 3.01, CI is 0.01, and CR is 0.012 (1.2%). As the CR is less than 10%, the pairwise comparisons are consistent.

Through the criteria weights and the idealized priorities, it is possible to get a ranking of the 27 combinations (Table 4). The goal after calculating the value of each combination is to group the spare parts and assign the most appropriate inventory management policy.

Table 4: Performance ranking - combinations

Criticality	Lead Time	Price	Ranking
High	High	High	0.9990
High	High	Medium	0.9448
High	High	Low	0.9379

Criticality	Lead Time	Price	Ranking
High	Medium	High	0.8611
High	Low	High	0.8436
High	Medium	Medium	0.8069
High	Medium	Low	0.8000
High	Low	Medium	0.7893
High	Low	Low	0.7825
Medium	High	High	0.4172
Medium	High	Medium	0.3629
Medium	High	Low	0.3560
Low	High	High	0.3433
Low	High	Medium	0.2890
Low	High	Low	0.2821
Medium	Medium	High	0.2793
Medium	Low	High	0.2617
Medium	Medium	Medium	0.2250
Medium	Medium	Low	0.2181
Medium	Low	Medium	0.2075
Low	Medium	High	0.2054
Medium	Low	Low	0.2006
Low	Low	High	0.1878
Low	Medium	Medium	0.1511
Low	Medium	Low	0.1442
Low	Low	Medium	0.1336
Low	Low	Low	0.1267

Implications and practical considerations

The main objective of this research is to compare the multi-criteria classification based on rules with the multi-criteria classification using AHP. In the first case, a decision tree was used. Through the support of the expert panel, the criteria were defined based on rules. In the second case, AHP is used to obtain the weights of each criterion and the idealized prioritization of the levels of each criterion.

The method proposed by Teixeira, Lopes, and Figueiredo (2018) does not require a large data set, which makes it easier and simpler to implement. The classification also involves the participation of company specialists (in defining the order and importance of the criteria and even in choosing the groups), which leads to greater involvement of the organization's human resources, which facilitates implementation. The disadvantage is that when expert judgment is required, subjective assessments are possible.

The multi-criteria classification using AHP has the advantage of being able to compare any criterion either quantitative or qualitative. The method also requires expert input to define a peer comparison matrix. This method requires more calculations than the previous one. Since the goal is to identify inventory management groups or ranking, the information obtained does not help too much at group definition, since it is difficult to understand which values should be included in each group.

Conclusions

Management of spare parts for manufacturing equipment affects the performance of maintenance management and, consequently, the productivity of organizations. Spare parts are essential for maintaining the production process operating efficiently, thus avoiding production and quality losses. On the other hand, high inventory levels are expensive, due to both capital immobilization and storage space. Spare parts classification is crucial to efficiently manage and control stock. Therefore, the selection of an appropriate multi-criteria classification method is important for the success of spare parts management.

This paper presents a comparative study between the use of the multi-criteria classification based on rules and the multi-criteria classification using AHP. With this study, it was confirmed that the method presented by Teixeira, Lopes, and Figueiredo (2018) is more easily applied in organizations. The decision tree does not imply the use of many calculations, which facilitates its practical application. In the case of AHP, more calculations are required making the implementation of the method more complex, especially for non-AHP specialists. The use of AHP would be more useful if the study implied a more significant number of criteria, as it would more objectively estimate the importance of each criterion. In this case, the order of importance of each criterion is quickly recorded without the use of calculations. AHP is not suitable to establish groups since what is obtained is a ranking. In order to group spare parts, groups must be created by distributing ranking scores into classes. The difficulty would be to define appropriate limits for these classes. Since an inventory management policy will be assigned to these groups, some additional considerations are required to help define the groups, i.e. some rules would have to be established. This would make the process more complicated. It was concluded that when the purpose is the classification and clustering of spare parts based on few criteria the multi-criteria classification based on rules is easier to implement and appropriate to support decision making concerning management of spare parts.

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