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CRITICALITY EVALUATION OF SPARE PARTS USING THE ANALYTIC HIERARCHY PROCESS WITH RATINGS

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ABSTRACT

Important spare parts should be kept in stock and their inventory properly controlled to replace worn and/or defective components with new ones and minimize downtime in various maintenance activities. However, the possession of spare parts in stock for ready availability (when necessary) may entail, in the case of expensive and rarely used parts, high inventory retention costs. In this work, an approach is presented to evaluate the criticality of spare parts using the AHP method with the use of ratings (Analytic Hierarchy Process Ratings Model). The structure of the elaborated decision hierarchy is related to the consequences caused by the failure of a spare part in the process, in case a replacement is not readily available with demand and supply attributes, segmenting the priorities by the Vital, Essential and Desirable criteria (VED). The proposed model was applied in very low turnover spare parts of an integral organization of an intensive capital company located in the South Fluminense, using the Saaty procedure for the definition of priorities through the software of free access Super Decisions, allowing the prioritization of the pieces to be stored and the establishment of differentiated management policies for each class.

Keywords: Multicriteria Analysis; Analytic Hierarchy Process; Ratings Model; Inventory; Spare parts.

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1. INTRODUCTION

Many capital intensive industries rely on the availability of their assets to manufacture their products. These are essential for productive processes and their downtime (unavailability) needs to be minimized, as they can: (i) loss of revenue (e.g. due to downtime in a production environment), (ii) customer dissatisfaction and possible associated claims (e.g. supply delays) or (iii) risk to the safety of persons, facilities and environment (for example, power stations). Generally, the consequences of asset downtime are very costly (Driessen et al., 2014).

To minimize downtime, various maintenance activities are performed. These activities will eventually require spare parts to replace worn and/or defective components with new ones.

Cavalieri et al. (2008) consider that in the case of unplanned shutdowns, typical of a corrective maintenance activity, downtime is composed of many elements that can strongly compromise the productivity of a plant. In addition to the downtime required to diagnose and remove the cause of failure, there are specific time elements associated with proper logistical support for maintenance activities: if the spare part is not available in stock, there may be delays in provisioning, such as the issuance of purchase orders, negotiation, delivery time, and that for specific items such as pieces made under drawing, can reach several weeks or months.

However, the possession of spare parts in stock for ready availability (when necessary) may entail, in the case of expensive and rarely used parts, high inventory retention costs (Cavalieri et al., 2008). These spare parts must be available in the right quantity and at the right time (Almeida et al., 2015). Almeida et al. (2015) point out that the management of these resources is one of the most critical tasks of Maintenance Management.

Gajpal et al. (1994) consider that a systematic and scientific approach to the management of spare parts can result in the minimization of inventory of spare parts and the downtime of the machine. They also consider the need to evaluate and specify the importance of items in the inventory, bearing in mind the specific uses of different spare parts. Factors such as replacement cost, availability, storage conditions, probability of failure of a spare part, downtime costs, among others, should be weighed during the management of spare parts inventories. In this context, the criticality of individual items should be considered, thus describing how crucial a spare part is (Stoll et al., 2015).

Stoll et al. (2015) suggest the criticality assessment of a spare part according to the risk in acquisition and storage or consequences caused by failure of the machine if the spare part is not available. In practice, the unsatisfactory situation is that all spare parts are traditionally acquired, stored and supplied according to an intuitive assessment and therefore their individual characteristics are not taken into account.

For these reasons, the objective of this article is to present an approach to evaluate the criticality of spare parts. For this, the AHP method will be used by means of ratings (Analytic Hierarchy Process Ratings Model).

The AHP method has been used in several decision-making scenarios with multiple criteria and some conflicting ones (such as the availability of the part and the cost associated with the stock). This choice is also justified due to its applicability, simplicity and ease (Saaty, 2001). The option of using classification by ratings has the advantage of allowing a quickly evaluation of a large number of alternatives, and the results are suitably close (Saaty, 2008).

This paper is organized as follows: Section 2 presents a review of the literature on spare parts criticality analysis and the AHP method. Section 3 presents the methodology and development of the AHP with ratings. Section 4 presents examples of application in spare parts of a capital intensive industry and data analysis. Finally, in section 5, the main conclusions and recommendations for future work are presented.

2. LITERATURE REVIEW

2.1 Maintenance and management of spare parts

Spare parts management positively influences maintenance management as it leads to greater reliability and availability of equipment and therefore has a direct impact on the profitability of the business (Almeida et al., 2015) specific problems in risk, reliability and maintenance context are described, such as location of backup units, sequencing of maintenance activities, natural disasters, operation planning of a power system network, integrated production and maintenance scheduling, maintenance team sizing and reliability acceptance tests. This chapter presents a multicriteria decision model with an illustrative application for most of these problems. Amongst the MCDM/A approaches considered for the illustrative applications in this chapter are: Multi-attribute utility theory (MAUT.

Almeida et al. (2015) consider that, as compared to other types of inventory models, as raw material for manufacturing processes, the dimensioning and management of spare parts inventories are much more complex tasks, considering that it is generally easier to predict the demand for manu-

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facturing inputs, especially when comparing their turnover. Production inventories generally follow market rules, but spare parts are required, based on failure rates and system reliability design.

Typically, when a failure occurs, the failed item is replaced with a spare item, which must be available. Sometimes the defective item is shipped for repair and subsequently returns as good as new to the stock of spare parts (Almeida, 2001).

The challenge of management is to decide on the economic convenience in holding and controlling the stock of a particular item, as there is a risk of increased inventory and, consequently, excessive storage costs. A common practice for effective inventory management is to group the spare parts according to some classification method (Hu et al., 2018).

2.2 Criticality of spare parts

Teixeira et al. (2017) consider that the classification of spare parts is a relevant step in guiding the entire management process, and many advantages can be obtained by appropriate classification. According to Huiskonen (2001) and Molenaers et al. (2012), there are two types of criteria to classify the criticality of spare parts: the criticality of the process - if its failure or malfunction results in serious consequences for the plant, for example the consequences related to loss of life, environmental contamination or loss of production; and control criticality - a spare part is considered critical if the possibility of ensuring the immediate availability of the part is difficult to control.

The classification of spare parts, according to their criticality, allows the identification of those that are more important, facilitating the use of different stock strategies for different classes of parts, besides prioritizing the most important items in the management of spare parts (Hu et al., 2018). Gajpal et al. (1994) argue that simple and straightforward procedures, such as the ABC analysis, according to the Pareto principle, and the FSN (Fast, Slow and No Moving) analysis, according to the stock turnover, have been used in practice to specify control policies and adjust inventory review periods. A great advantage of these analyzes is the simplicity of application: spare parts can be classified using only one criterion (Stoll et al., 2015).

Other commonly used tools are qualitative methods. The VED (Vital, Essential and Desirable) analysis is a well-known qualitative method that classifies spare parts according to their criticality, based on consultation with maintenance specialists (Cavalieri et al., 2008; Roda et al., 2014). According to their feedbacks, spare parts are classified as vital (V), essential (E) and desirable (D) items. The VED analysis uses several criteria in the classification of a spare part and, despite its apparent simplicity, the structuring of the analysis can be difficult, since the classification can suffer with the subjective judgments of the users (Cavalieri et al., 2008).

The use of various criteria as a basis for classification is especially useful for spare parts having several distinct characteristics, in addition to price and volume of demand (Huiskonen, 2001). Criticality becomes relevant as it allows relating the consequences of the failure of a spare part in the process, in case a replacement is not readily available, with other aspects of control of the situation, which include predictability of failures, availability of spare parts suppliers, delivery times, etc.

2.3 AHP to evaluate the criticality of spare parts

AHP is one of the most appropriate methods for developing this model, because it makes use of paired comparisons to find out which is the most critical spare; uncertainty does not play a critical role in the criteria and a qualitative and quantitative combination of data can be used (Sabaei et al., 2015).

Partovi and Burton (1993) were the first to propose the use of AHP as a tool to classify maintenance items (Roda et al., 2014). Gajpal et al. (1994) proposed a VED classification model based on the use of the AHP procedure to limit the problem of subjective judgments. The VED-AHP analysis proposed by the authors identifies three factors that influence the criticality of the spare parts (the type of parts needed, the lead time for the provision of spare parts and the availability of the production facility when an original part fails and a spare part is required), and the AHP results in a composite index, which is adopted as a comprehensive score to define the VED classification index.

Braglia et al. (1986) applied the AHP together with the Reliability Centered Maintenance, making use of decision diagrams in order to classify spare parts and decide between different storage policies. They preliminarily assessed the criticality of the parts, considering three alternative scenarios in the model (critical, important and desirable) and criteria (e.g. loss of production, quality problem, domino effect, etc.) and then three decision trees, considering the supply characteristics (lead time, number of suppliers, possibility of repair), inventory problems (cost, storage space, obsolescence) and utilization rate (number of items applied, redundancy, frequency of failures) to classify and redefine the stock level of spare parts.

Another contribution is the work of Molenaers et al. (2012). In this work, the authors developed a multicriteria classification method to evaluate the criticality of spare

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parts, considering the criticality of the equipment, the probability of failure, the spare time, the number of suppliers, the availability of technical specifications and the type of maintenance. Based on these characteristics, the spares were classified into four criticality classes: high, medium, low and none.

Antosz and Ratnayake (2019) explain how to evaluate and prioritize the criticality of spare parts to improve the availability and reliability of manufacturing systems, considering a decision hierarchy with logistic criteria (acquisition cost, lead time, and number of suppliers) and (equipment category, spare time, complexity, type and frequency of failure, and qualification of the maintenance team). Subsequently, they perform sensitivity analysis based on comparisons between peers, maintenance and logistics, as an alternative means to study how final selection is made and how different criteria and subcriteria contribute to the final priorities.

2.4 The AHP process

Saaty (2008) states that in order to make a decision, it is necessary to know the problem, the necessity and purpose of the decision, the decision criteria, its subcriteria, affected parties and affected groups and the alternative actions to be taken. It also guides in determining the best alternative or, in case of resource allocation, prioritizing the alternatives, in order to allocate the appropriate portion of resources.

Over the years, AHP has consolidated itself on scientific research as a flexible implementable tool to integrate qualitative and quantitative aspects, as well as assign weights to different criteria when its importance is not the same (Roda et al., 2014). One of the main advantages of AHP is that it recognizes subjectivity as inherent in decision problems and treats it scientifically, using value judgment (Pereira et al., 2017).

To make a decision in an organized way to generate priorities, it is necessary to decompose the decision in the following steps (Saaty, 2008):

1. Define the problem and determine the type of knowledge you want

The general objective to be achieved is the decision goal, followed by the criteria associated to the decision problem and the available alternatives that best fit the problem studied (Pereira et al., 2017).

2. Structure the decision hierarchy

At the top, the purpose of the decision is defined, then the objectives from a broad perspective, through the intermediate levels (criteria on which the subsequent elements depend upon) to the lowest level (which is usually a set of alternatives) (Saaty, 2008). Commonly, the structuring of the hierarchy is represented in tree format, as shown in figure 1.

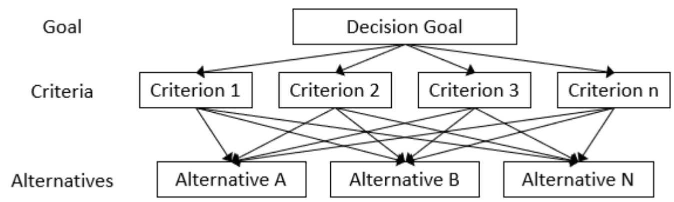

Figure 1. Generic hierarchical structure of decision problems.
Source: (Pereira et al., 2017).

The choice and relevance of the criteria to evaluate the alternatives can be defined through consultation with specialists, or through identification in the literature of which criteria have already been used in published articles.

3. Construct a set of peer comparison matrices

Each element at a higher level is used to compare elements at the level immediately below, and those objectives or criteria are compared to each other (Saaty, 2008).

For the comparisons, a scale of numbers was used to indicate how much more important or dominant an element is in comparison with another element, with respect to the criterion or property in relation to which they are compared (Saaty, 2008). Table 1 presents the value scales for parity judgments, ranging from 1 to 9, and is called the Saaty Fundamental Scale. If activity "i" has an assigned intensity of importance when compared to activity "j", then "j" will have the reciprocal value when compared to "i" (Saaty, 2008).

The results of the comparisons are presented as a matrix of judgments A.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ 1/a_{n1} & 1/a_{n2} & \cdots & 1 \end{bmatrix} \quad \text{Equation 1}$$

4. Use the priorities obtained in comparisons to weigh priorities at the level immediately below

This should be replicated for each element. Then, for each element in the level below, its weighted values must be added in order to get its general or global priority. This process continues to determine the additional weights until the final priorities of the alternatives at the lowest level are obtained. In this model, all nodes are compared to

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each other in pairs to establish priorities that require *n.(n-1)/2* comparisons (Saaty, 2008). Decisions are determined by a single number for the best result or by a priority vector that provides a proportional ordering of the different possible outcomes to which resources can be optimally allocated, subject to both tangible and intangible constraints (Greco et al., 2016).

Saaty (2008) presents another method to obtain priorities for the alternatives, establishing classification categories. This method, called the AHP Ratings Model, involves making comparisons matched with the criteria just above the alternatives, known as the coverage criteria, where categories are assigned intensities. These intensities may vary in number and type. For example: high, medium and low; more than 15 years, between 10 and 15, between 5 and 10 and less than five (Greco et al., 2016).

The priorities of each category are derived through paired comparisons in relation to the intensities (Greco et al., 2016). Alternatives are classified one at a time in each category based on these intensities. Next, the overall classification priority is determined by weighing the priorities of each category of the other criteria and is added to the weighted intensities of each alternative.

Both methods do not provide exactly the same priorities (Saaty, 2008). The relative model, which is the method in which the alternatives are compared against each other under the various criteria, is more precise. The AHP Ratings Model has the advantage of evaluating a large number of alternatives quickly and the results are appropriately close (Saaty, 2008).

The AHP allows the analyst to assess the quality of the judgments through the I_R inconsistency index. Judgments can be considered acceptable if $I_R \leq 0.1$. In cases of inconsistency, the evaluation process for the matrix that presents inconsistency is immediately repeated. An inconsistency index greater than 0.1 requires further investigation into the consistency of the decision-maker's judgments (Bevilacqua; Braglia, 2000).

3. METHOD

In this work, an AHP Ratings Model is proposed to carry out the analysis of criticality of spare parts. The proposed model uses the Saaty procedure for prioritization through the free access software Super Decisions.

A sample of spare parts from an organization that is part of an intensive capital company located in the South of Brazil was selected for convenience in evaluating the priorities (alternatives). The organization currently has more than 230,000 registered items to maintain its equipment and facilities. Of these, about 30,000 items have a regular balance in stock. The vast majority of items (61%) are extremely slow moving, with consumption lower than 1 piece/year in the last five years.

The criteria were chosen after a discussion with consultants and specialists of the organization, including, maintenance engineers, materials planning analysts and maintenance process managers, material planning, and controller. The criteria use quantitative and qualitative parameters with representativeness of different interests of different stakeholders of the sectors involved in the process of replacement of spare parts.

First, the needs of each sector and project guidelines were analyzed, with a view to maximizing inventory availability for maintenance and minimizing inventory costs.

The sources of data collection used were internal documentation, records of the company's management systems (Enterprise Resource Planning (ERP) - SAP - and Computerized Maintenance Management System (CMMS), observa-

Table 1. Saaty fundamental scale.

Intensity of Importance	Definition	Explanation
1	Equal importance	Both activities contribute equally to the goal.
3	Small importance of one over the other	Experience or judgment favors one activity slightly in relation to the other.
5	Large or essential importance	Experience or judgment strongly favors one activity over another.
7	Significantly large or demonstrated importance	One activity is strongly favored over the other. Its dominance can be demonstrated in practice.
9	Absolute Importance	Evidence that favors one activity over another is of the highest possible order of affirmation.
2, 4, 6 e 8	intermediate values	When you are looking for a compromise condition between two settings.

Source: Prepared from (Saaty, 2008).

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tions and interviews with employees involved in the maintenance and management of inventories.

After choosing the criteria, the hierarchical tree was elaborated and the ratings were assigned, structuring the analysis in the Super Decisions. Then the composite priorities or weights for each category and their ratings were calculated to use them to measure the criticality of a spare part.

4. RESULTS AND DISCUSSION

4.1 Definition of criteria

In this article, the vital, essential and desirable criteria and the subcriteria (as coverage criteria) with the ratings are used to assess the criticality of the spares. The selection of the subcriteria for the evaluation of the criticality of spare parts relates the consequences caused by the failure of a spare part in the process, in case a replacement is not readily available, with demand and supply attributes.

Chart 1 summarizes the subcriteria (coverage criteria) and the ratings used in an organization that is part of a capital intensive company located in the south of the state of Rio de Janeiro for the evaluation of 10 items randomly selected.

Chart 1. Elements of the Critical Matrix

Coverage Criteria	Ratings
Lead time: Understands material procurement time as entered in the material master.	LT <= 45 45 < LT <= 60 60 < LT <= 90 90 < LT <= 120 LT > 120
Consumption variability (CV): Weighted by the coefficient of variation (CV), which is obtained by the ratio between the standard deviation and the mean of the consumption of the spare part according to the magnitude (quantity requested) and the number of occurrences (monthly periodicity).	CV <0,5 0,5 <= CV < 1,0 1,0 <= CV < 2,0 2,0 <= CV < 3,0 CV >= 3,0
Purchase cost: It is the cost referring to the maximum value between the unit value of the spare part (periodic internal price) and the amount of the minimum purchase lot.	CA < 5 5 <= CA < 20 20 <= CA < 150 150 <= CA <500 CA >= 500
Resupply form: It concerns the existing supply alternatives for maintenance and material planning professionals.	Internal Contract On demand Imported
Safety: A failure has a safety consequence if it causes a loss of function or other damage that could injure or kill someone.	Yes No
Environment: A failure has an impact on the environment if it causes any loss of function or other damage that could lead to violation of any known environmental regulations or standards.	None Low Moderate Critical Catastrophic
Quality: A failure has a consequence in the quality if it causes any loss of function or other damage that causes problems in the quality of the product or service.	
Production: A failure results in production if it causes any loss of function or other damage that disrupts production.	

Source: Prepared by the authors from (Valentim et al., 2018).

4.2 Application of the AHP method

The hierarchical structure composed of the definition of the overall objective, criteria, subcriteria and ratings for criticality of spare parts is illustrated in figure 2.

This hierarchy was replicated in Super Decisions, and then the sets of peer comparison matrices were constructed. Pairwise comparison matrices obtained for vital, essential and desirable criteria generated the priorities with the inconsistency index observed in figure 3.

In this first analysis, the comparison obtained a consistency index of 0.00000, showing that the comparative values are within the acceptable value (below 0.1). The order of preference of the criteria is Vital > Critical > Essential.

Comparison matrices alongside subcriteria (coverage criteria) were replicated for each criterion. As an example, Figure 4 shows the comparison related to the Vital criterion. It was also done with the other two criteria.

It is observed that the inconsistency index for the coverage criteria (subcriteria) (0.00000) is also within the acceptable value, and the order of preference among the criteria is: Safety = Production > Quality > Lead time = Supply source = Environment > Cost = Variability of Consumption.

Subsequently, the ratings associated to each coverage criterion (subcriteria) were inserted and the pairwise comparisons were done, as exemplified in figure 5.

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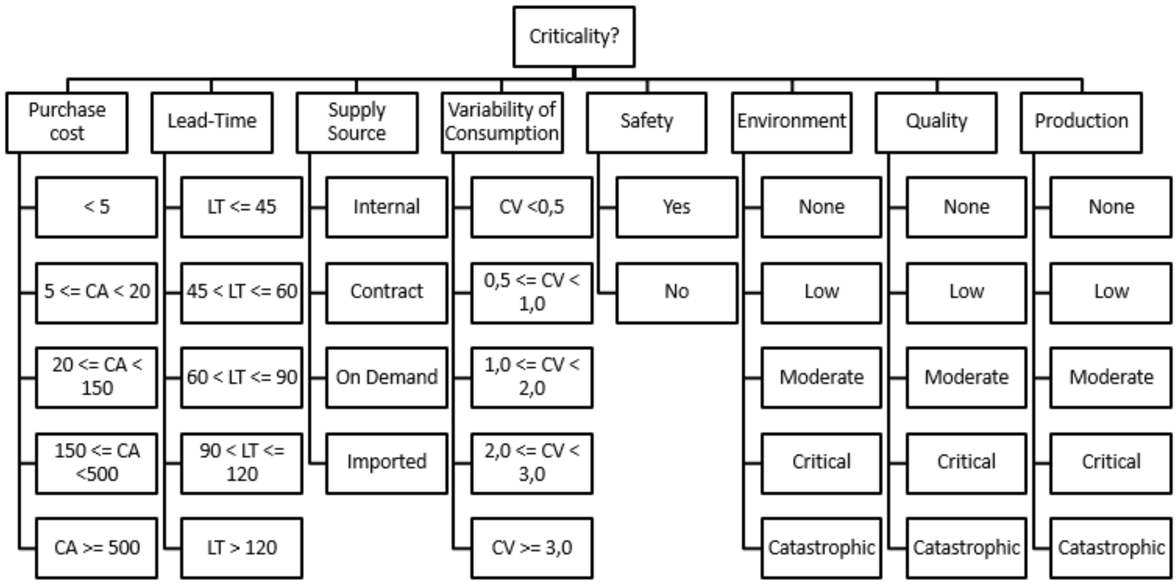

Figure 2. Hierarchical structure of the AHP Ratings Model for criticality classification of spare parts.

Source: Prepared by the authors

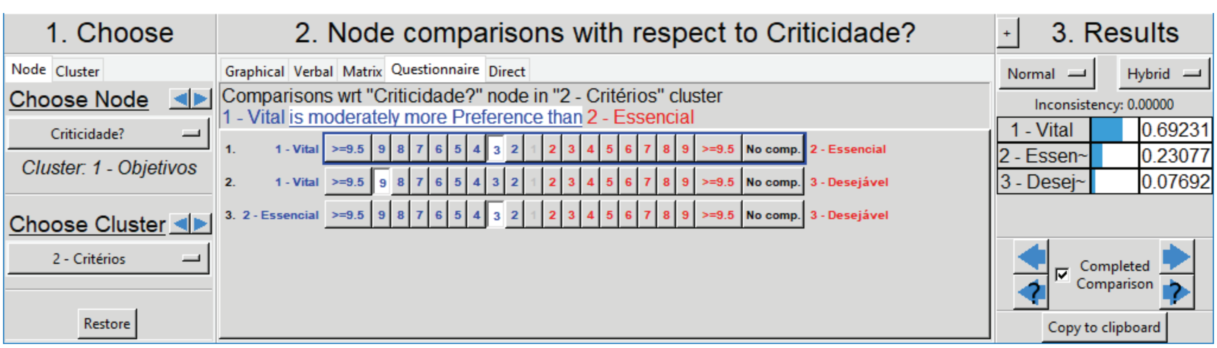

Figure 3. Comparison with criticality criteria.

Source: prepared by the authors..

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Figure 4. Comparison with the coverage criteria for the Vital criterion.

Source: Prepared by the authors

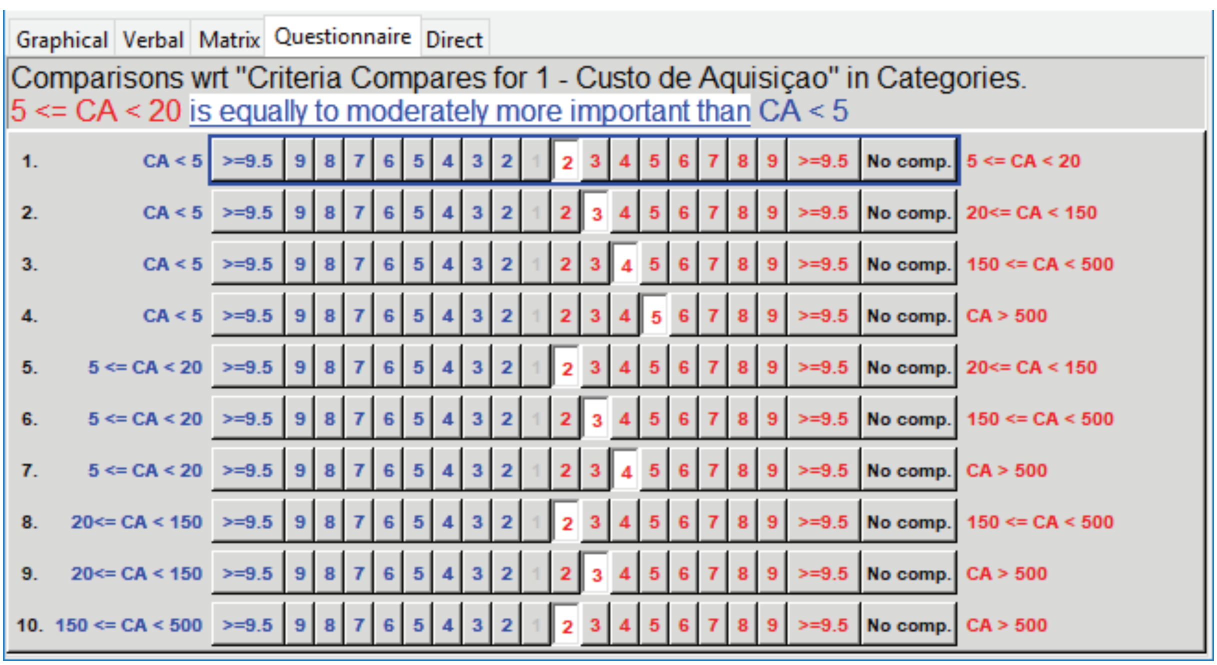

Figure 5. Pairwise comparison of the ratings of coverage criterion cost.

Source: Prepared by the authors

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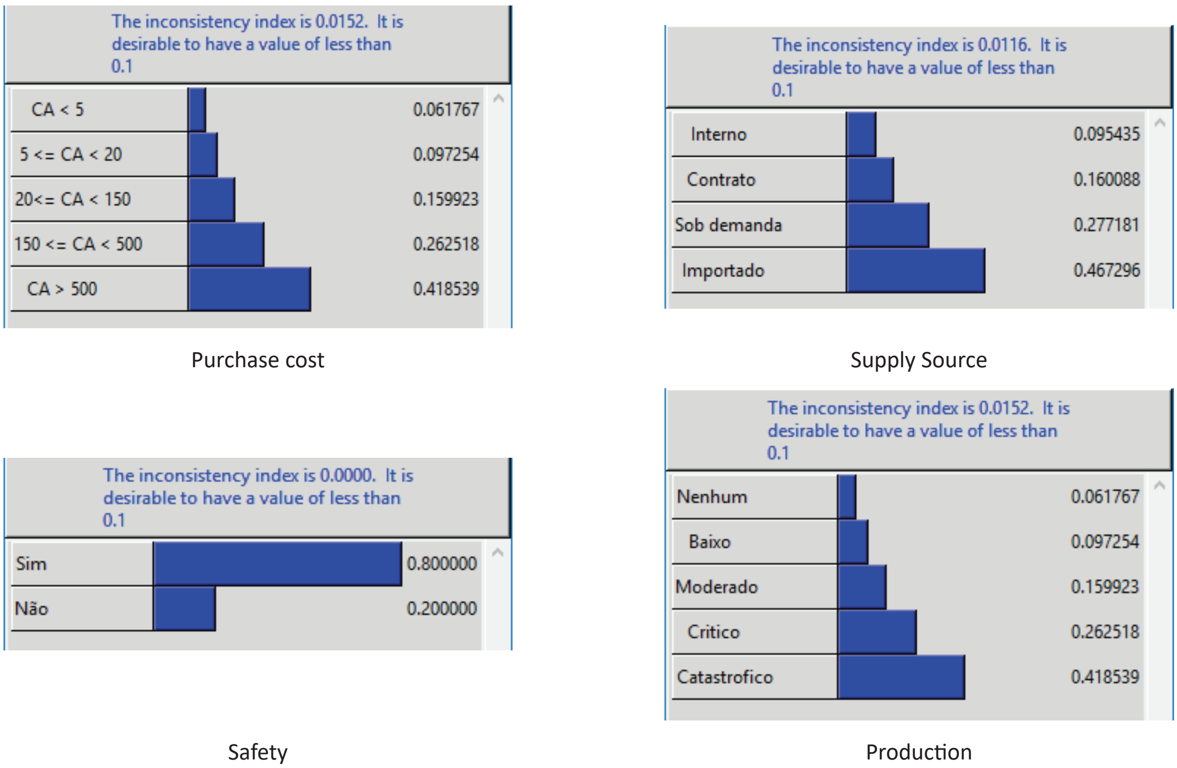
Chart 2. Ranking priorities of coverage, acquisition cost, supply source, safety, and production criteria.



Source: Prepared by the authors (2018).

Super Decisions Ratings

	Priorities	Totals	1 - Custo de Aquisiç 0.049960	2 - Lead time 0.086680	3 - Fonte de suprim 0.086680	4 - Variabilidade de 0.049960	5 - Segurança 0.244600	6 - Meio Ambiente 0.086680	7 - Qualidade 0.150840	8 - Produção 0.244600
Peça #1	0.119132	0.621900	5 <= CA < 20	60 < LT <= 90	Sob demanda	CV >= 3,0	Sim	Baixo	Moderado	Critico
Peça #2	0.156848	0.818783	5 <= CA < 20	LT > 120	Interno	CV >= 3,0	Sim	Nenhum	Catastrofico	Catastrófico
Peça #3	0.156429	0.816595	5 <= CA < 20	LT > 120	Sob demanda	CV >= 3,0	Sim	Moderado	Critico	Catastrófico
Peça #4	0.105297	0.549677	CA > 500	45 < LT <= 60	Sob demanda	CV >= 3,0	Não	Nenhum	Catastrofico	Critico
Peça #5	0.095522	0.498646	20<= CA < 150	LT > 120	Interno	2,0 <= CV < 3,0	Sim	Baixo	Nenhum	Baixo
Peça #6	0.089223	0.465764	150 <= CA < 500	LT <= 45	Importado	CV >= 3,0	Não	Nenhum	Moderado	Critico
Peça #7	0.065258	0.340660	20<= CA < 150	90 < LT <= 120	Sob demanda	CV >= 3,0	Não	Nenhum	Baixo	Baixo
Peça #8	0.045174	0.235817	5 <= CA < 20	60 < LT <= 90	Sob demanda	CV < 0,5	Não	Nenhum	Nenhum	Nenhum
Peça #9	0.122653	0.640277	CA < 5	LT > 120	Sob demanda	CV < 0,5	Sim	Critico	Baixo	Critico
Peça #10	0.044465	0.232120	CA < 5	LT <= 45	Contrato	CV >= 3,0	Não	Nenhum	Nenhum	Nenhum

Figure 6. Ratings for 10 spare parts.
Source: prepared by the authors (2018).

Five ratings were prepared for the criteria of acquisition cost, lead time, consumption variability, environment, quality and production. For the supply and safety source criteria, four and two ratings were prepared, respectively.

In all, 67 comparisons were made. The results of the ratings priorities with the inconsistency indices are presented in Chart 2.

It is observed that the indexes of inconsistency found were 0.0152 for the categories with five ratings (acquisition cost, lead time, consumption variability, environment, quality and production), 0.0116 for the source category of resupply and 0.0000 for safety.

By assigning the weights to the criteria, coverage criteria (subcriteria) and ratings, the alternatives for assessing their priorities are added, as shown in figure 6.

The global priority vector defined for the 10 spare parts is shown in figure 7.

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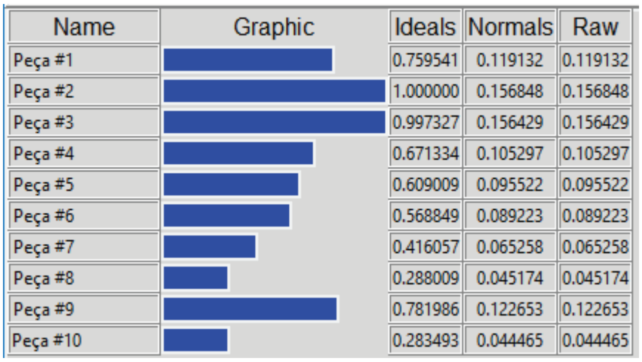

Name	Graphic	Ideals	Normals	Raw
Peça #1		0.759541	0.119132	0.119132
Peça #2		1.000000	0.156848	0.156848
Peça #3		0.997327	0.156429	0.156429
Peça #4		0.671334	0.105297	0.105297
Peça #5		0.609009	0.095522	0.095522
Peça #6		0.568849	0.089223	0.089223
Peça #7		0.416057	0.065258	0.065258
Peça #8		0.288009	0.045174	0.045174
Peça #9		0.781986	0.122653	0.122653
Peça #10		0.283493	0.044465	0.044465

Figure 7. Vector priority for 10 spare parts.

Source: Prepared by the authors (2018).

For these items, the most critical piece is part # 2. The final global priority order is displayed as: #2 > # 3 > #9 > #1 > #4 > #5 > #6 > #7 > #8 > #10.

5. CONCLUSIONS

This work presents, through a practical example, an approach for the systematic evaluation of the criticality of spare parts, using the AHP method with the use of the Analytic Hierarchy Process Ratings Model. In the analysis of criticality, structured in the software Super Decisions, the priorities of 10 spare parts of very low turnover were identified. The elaborated decision hierarchy allows the segmentation of priorities by the Vital, Essential and Desirable criteria (VED), and the evaluation by means of demand and supply subcriteria (lead time, consumption variability, purchase cost and supply source) and criteria of operational risk (safety, environment, quality and production).

While demand and supply subcriteria weigh interests in order to assist inventory policies, operational risk subcriteria weigh interests to help mitigate operational risk by assessing the consequences of the failure or malfunction of the spare part at its place of application. The subcriteria selected by the organization's experts are in line with the criteria found in the works of Braglia et al. (1986), Roda et al., 2014 and Antosz and Ratnayake (2019), presented in the literature review.

This approach will allow analysis of criticality for other spare parts of the organization, categorizing them into classes by weighing the ideal priorities of spare parts and VED criteria - table 2 - allowing the establishment of differentiated management policies for each class.

Table 2. Segmentation of the criticality of spare parts in classes.

Ideal spare part priority	Class
>= 0,69231	Vital
>= 0,23077 e < 0,69231	Essential
< 0,23077	Desirable

Source: Prepared by the authors (2018).

The work can be extended to include other classification schemes, such as classification for inventory control and for forecasting demand (Hu et al., 2018). These classifications enable the selection of appropriate inventory policies for different groups of spare parts, assisting decision making in resource prioritization and in establishing controls with a focus on maximizing the availability of spare parts for maintenance and minimizing inventory costs.

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