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A review of spare parts supply chain management

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The particular characteristics of spare parts have prompted several authors to provide substantial results for effective spare parts supply chain management. In this context, the purpose of this paper is to present the significant contributions that researchers have proposed, over time, for the management of spare parts supply chain. The literature has shown that the particular characteristics of spare parts have a significant impact on inventory performance and customer demand fulfillment. For this reason, most of the contributions were focused on spare parts classification methods, forecasting methods and inventory optimization. The focus of researchers on some areas of spare parts management allowed us to identify some promising perspectives that were not developed in literature, such as the development of performance measurement frameworks for spare parts supply chain and the measurement of organizational maturity.

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INTRODUCTION

The spare parts business forms an essential source of revenues in many sectors, such as automotive, IT industry, medical and industrial equipment [1]. However, the activity is usually difficult to handle because of intensified competition, globalization, technological evolution and emerging spare parts markets.

Besides, the spare parts have some particular characteristics that significantly influence all the supply chain processes [2]. Therefore, the manufacturers and the distributors of spare parts have to implement effective and responsive systems, to fulfill the customers' needs and to improve the operational excellence and the financial performance in a prospective and optimal manner.

The literature has principally been limited to inventory management and forecasting methods to ensure the availability of spare parts and to optimize the inventory [3]. However, the literature has devoted little attention to the other areas of spare parts supply chain management, such as the organization strategy [1], the supplier selection [4] and the process maturity [5].

In the present paper, we propose a literature review of the main contributions related to spare parts supply chain management. We focus on the

following areas: Spare parts classification methods, inventory management, forecasting methods and performance measurement of spare parts supply chain.

RESEARCH METHODOLOGY

The literature review was carried out through a process of articles selection "Figure1", based on the following bibliographic databases: Google Scholar, Science Direct and Scopus.

The first step of the process was the identification of a set of articles through the combination of keywords related to the management of spare parts supply chain. The research led to 148 articles. We selected 75 articles after removing duplicates and screening titles. Then, we selected 60 articles after reading abstracts. Afterwards, we excluded 10 articles after full reading, and we included 50 articles in the present review.

The included articles allowed us to determine the issues that have received great attention from researchers in the field of spare parts management. Most of the contributions have focused on inventory management and forecasting methods because of the special features of spare parts that have a significant influence on inventory performance.

SPARE PARTS CHARACTERISTICS

To understand how companies can better respond to customer demand, we first need to identify the factors that prevent them [6]. Most of the managers in spare parts companies believe that investment, strategic orientation and internal organizational communication are not the significant obstacles to their businesses continuous improvement.

They believe that the main obstacles are the stability of spare parts supply chain, relationships with suppliers, information system, data management, supply chain visibility, warehouse management, inventory management and capacity management.

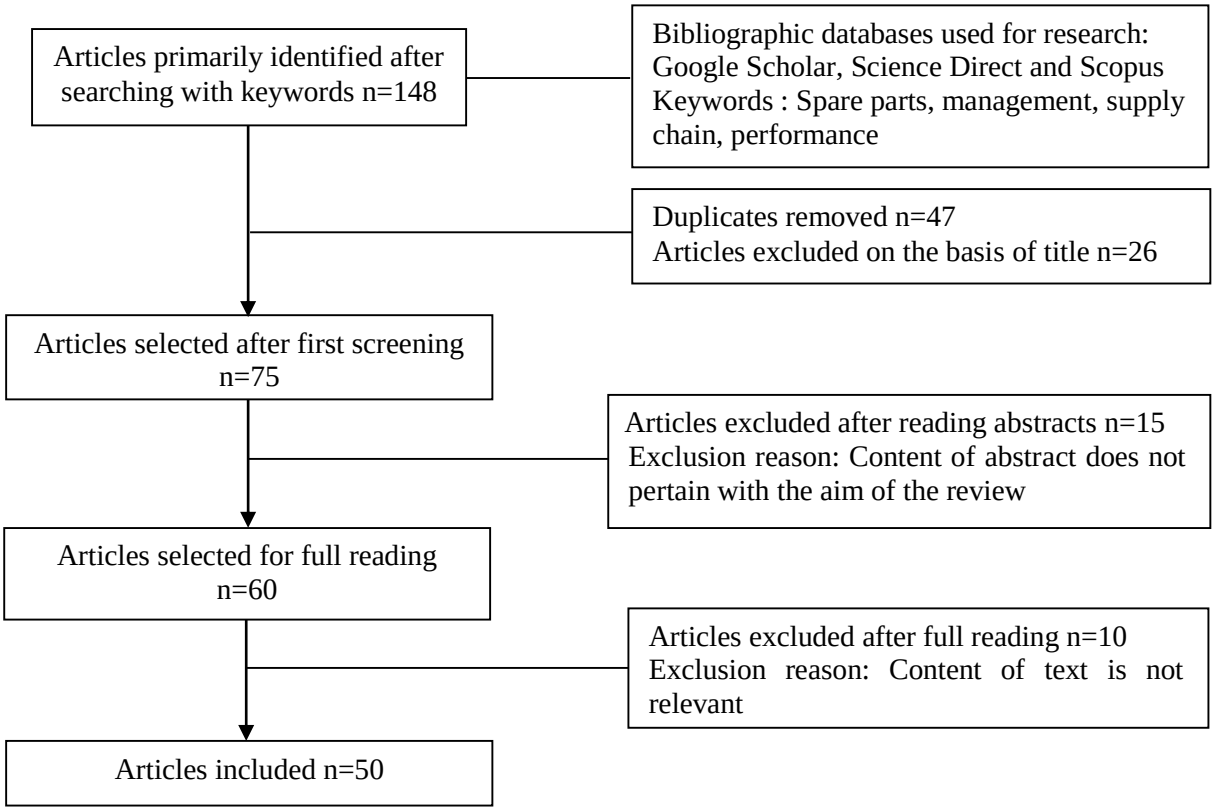

Figure 1. Process of articles selection

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These obstacles are related to the particular characteristics of spare parts, such as the multiplicity of references [7] due to the creation of new ranges or the entry into new markets, the durability of spare parts, the heterogeneity of sales, the risk of obsolescence and the intermittency of customers' demand [8]. Spare parts are also distinguished by different costs that can be very expensive [9], [10]. Therefore, the carrying cost of inventory can also be significant.

Spare parts also require a high service level. It is necessary to ensure the availability of spare parts, in order to meet the customer need at the right time.

The particular characteristics of spare parts have created a strong need for the implementation of appropriate techniques to manage the complexity of spare parts supply chain. In this context, the literature has presented the classification of spare parts as an essential and useful step to facilitate the decision-making process [11] and to help managers to focus on the most important items.

SPARE PARTS CLASSIFICATION METHODS

The literature has proposed several quantitative and qualitative classification methods that use a set of criteria for effective inventory management. The most popular criteria are criticality, volume of demand, value of spare parts, time of replenishment, availability of suppliers and variability of demand [12], [13], [14], and [2].

The degree of criticality differs according to the importance of the spare part. If the failure requires immediate repair and the spare part needs to be replenished as soon as possible, it will be a "high criticality". If the failure can be tolerated for a short time and the spare part needs to be replenished in a short time, it will be a "medium criticality". If the failure can be tolerated for a longer time and the spare part can be replenished in a more extended time, it will be a "low criticality".

The volume of demand is an important criterion assessed through the total amount of sales in a specified period. The value of spare parts is also an important criterion to take into account when making decisions regarding the stock level. Managers generally try to reduce the number of expensive spare parts held in stock. However, they must be careful and store a certain amount of these spare parts to fulfill customer demand.

The literature has presented many spare parts classification methods. Gajpal et al. [15] proposed an analytical classification model "VED" that defines three groups of spare parts (vital, essential and desirable) and uses criticality as a single criterion. The model is based on the use of the analytic hierarchy process (AHP) for the evaluation of criticality.

Sharaf and Helmy [16] proposed a similar approach. They defined four groups of spare parts (vital, very essential, important and desirable). The approach uses many criteria such as demand volume, demand value, criticality, supply characteristics and supply uncertainty.

The famous ABC method was also used for a single criterion "demand volume" [17] and for several criteria "demand volume/ value, criticality, supply characteristics/ uncertainty", on the basis of several methods such as weighted linear optimization [18], [19], [20] and artificial neural networks [21].

Syntetos et al. [22] and Boylan et al. [23] proposed a quantitative classification based on demand through a two-dimensional matrix based on demand variability and demand frequency. Molenaers et al. [24] proposed a classification method based on criticality. The proposed classification converts the criteria that affect the criticality of an item, into a single score presenting the criticality level. Then, the obtained criticality level is used to rationalize the efficiency of the spare parts inventory policy. The model offers the multi-criteria classification problem in a logic decision diagram where AHP is used to solve the multi-criteria decision sub-problems at diagram decision nodes.

Ben Jeddou [25] proposed a multi-criteria classification based on Ng model. The method was applied in a company that sells a range of automotive spare parts. Before, the company used the traditional ABC classification based on the annual use value (AUV) as a single criterion. However, the ABC classification gave little

satisfaction, which pushed the company to apply the multi-criteria classification based on Ng model. The company incorporated many criteria such as profit margin, annual number of orders, number of customers, and considered an order of importance for each criterion. The author pointed out that the multi-criteria classification is flexible according to the needs of each manager for changing classification criteria or integrating new criteria.

Despite the existence of several classification methods, the empirical application of these methods is still limited by obstacles such as data availability [2]. There is a strong need for case studies describing the application of classification methods and the problems faced during their implementation.

INVENTORY MANAGEMENT AND DEMAND FORECASTING

As already mentioned, researchers in the spare parts management field have focused on inventory management and demand forecasting because of the particular characteristics of spare parts. Several models for inventory management and demand forecasting have been developed in order to increase the level of service and to minimize costs.

The overview of the main contributions related to spare parts inventory management is presented in Table 1. Researchers have focused mainly on mathematical models that optimize spare parts inventory levels, minimize the inventory cost, and simultaneously lead to a high service rate. Spare parts obsolescence has also been discussed in literature since it forms a high risk for many companies because of the continuous technological evolution. The literature has also presented other contributions related to inventory control and stocking policies to deal with the criticality of spare parts demand.

The demand forecasting techniques are summarized in Table 2. Most methods are modifications or alternatives to others.

Table 1. Spare parts inventory management overview

Research field	The main purpose of publications	Authors
Inventory management	a. Mathematical approaches to optimize spare parts inventory management b. Obsolescence management c. Order and stocking policies d. Inventory control e. Inventory levels	Cobbaert and Van Oudheusden [26], Dekker et al. [27], Kennedy et al. [3], Teunter and Klein Haneveld [28], Kalchschmidt et al. [29], Aronis et al. [30], Caglar et al. [31], Chang et al. [32], Wong et al. [33], Porras and Dekker [34], Louit et al. [35], Topan et al. [36], Turrini and Meissner [37]

Table 2. An overview of forecasting methods applied to spare parts

Author (s)	Category	Forecasting method
Makridakis et al. [38]	Time series	a. Exponential smoothing b. Moving average
Altay et al. [39]	Modification of time series	Holt and Holt-Winters modified
Croston [40]	Croston	Croston's method
Syntetos and Boylan [41], Teunter et al. [42]	Modification of Croston's method	a. Approximation, SBA b. Alternative to Croston's method
Snyder [43], Willemain et al. [44]	Bootstrapping	Bootstrap
Kalchschmidt et al. [45], Kalchschmidt et al. [29]	Aggregation/ disaggregation of demand	Filtering data

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Altay et al. [39] proposed a modification of Holt's double exponential smoothing method [46] to forecast intermittent demand. The validation of the modification was done through a real data set of aircraft spare parts demand.

Croston [40] modified the exponential smoothing and the moving average methods. The author showed that these methods are not effective when there are many periods with zero demand. Croston proposed to treat separately the size of orders and the intervals between them, and to combine their exponentially weighted moving averages to achieve a demand forecast per period.

Croston's method was also modified twice [41], [42]. The authors pointed out that Croston's method is not suitable for dealing with obsolescence problems. They proposed an alternative to this method that updates the probability of demand instead of demand interval. The advantage is that the probability of demand can be updated each period, while the demand interval can only be updated in a period with positive demand.

Other variants of Croston's method are suggested in the literature as well. In a comparative study, Teunter and Sani [47] showed that the modifications of Syntetos are the most promising ones. Eaves and Kingman [48] also showed that most of the modifications are, on average, more effective than traditional methods, but not suitable for all situations.

The Bootstrap method was also applied to forecast intermittent demand [43], [44]. It represents an interesting alternative to Croston's method when short historical data limit the accuracy of time series methods. Jung et al. [49] modified the Bootstrap method by proposing a new method that takes into account the intermittency of demand for better improvement of forecasting performance.

Romeijnders et al. [50] proposed a two-step forecasting method that considers both the demand for spare parts and the type of component repaired. The method updates separately the average number of spare parts required per repair and the number of repairs. The method was tested in the aviation industry through a service provider. The results showed that the two-step method is one of the most accurate forecasting methods and performs better than Croston's method.

Other works focused on filtering data to separate constant demand from sporadic demand [45] by applying a single exponential smoothing to constant demand data, and a modification of Croston's method to intermittent demand data [29].

Other models treat the value of information collected about customers' demand such as Verganti's model [51], which considers preliminary information collected from customers as a driver for forecasting intermittent demand.

Demand forecasting is undoubtedly an essential step to ensure the availability of spare parts. For this reason, it has received great attention from researchers in the field of spare parts management [52]. However, the intermittent nature of spare parts demand is still a major obstacle to the accuracy of various forecasting methods applied to the context of spare parts.

PERFORMANCE OF SPARE PARTS SUPPLY CHAIN

The research related to the performance measurement of spare parts supply chain has been limited to the identification of some key performance indicators. Barkawi and Partners GmbH [53] listed, through their study on spare parts logistics, a set of key performance indicators used by spare parts providers: On-time delivery performance, inventory turnover, cycle time, service level, stock availability, fill rate, accuracy of delivery, accuracy of forecasts, inventory level, complaint rate and customer satisfaction.

De Leew and Beekman [54] provided an empirical study into performance measurement in the automotive spare parts supply chain. They investigated several companies (Importers, distributors and dealers) that play an important role in the distribution of spare parts in the dependent channel. They also checked results with an independent distributor.

The investigation aimed to find out which dimensions were relevant for companies and which indicators were the most measured. Authors provided a set of indicators that were important according to the interviewees: Availability rate, stock-out, lead time, delivery frequency, completeness, correctness, regularity and punctuality.

Cuthbertson and Piotrowicz [55] proposed a framework to analyze the supply chain performance measurement systems. The framework application was illustrated by the single case study of the global automotive supply chain of Jaguar spare parts, run by Unipart. Authors pointed out that the whole supply chain is designed to increase spare parts availability at every geographical location.

The proposed key performance indicators are essential given the intensified competition in the spare parts market, the particular characteristics of spare parts and the service requirements in terms of service quality and long-time availability of spare parts. However, it is essential to take into account other performance dimensions and indicators to increase the visibility of the entire spare parts supply chain.

CONCLUSION

The main objective of this review is to present a summary of the contributions provided by literature about the management of spare parts supply chain. As a result, we have identified some promising perspectives that constitute a fertile field of study, such as the development of performance measurement frameworks for the spare parts supply chain and the measurement of organizational maturity.

We propose for future studies to focus more on the performance measurement of spare parts supply chain, given that the particular characteristics of spare parts largely affect the management of supply chain processes for manufacturers and distributors of spare parts. Hence, it is of paramount importance to control the spare parts supply chain processes and to evaluate the achievement of objectives for better improvement of the whole supply chain performance.

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