CHAPTER 2: LITERATURE REVIEW

Introduction

This chapter discusses the phenomenon of inventory management and more specifically the literature revolving around inventory management of spare parts in the aviation industry in general. Furthermore, it discusses optimisation of spare parts industry within the context of maintenance process of air crafts, and presents comprehensive discussion of models related to spare parts inventory management.

Inventory Management

The inventory management seeks to keep available the products that are required for the company and for the customers, so it implies the coordination of the purchasing areas, manufacturing distribution. According to Cai, Li, and Chen, (2017) Inventories are accumulations of raw materials, supplies, components, work in progress and finished products that appear in numerous points along the production and logistics channel of a company. This leads us to determine that there are different products that are maintained in the companies in a way that ensures the operation of the same, therefore it is imperative to determine each of these elements, according to their classification.

The first is the raw materials are all those products in their raw or unmodified state extracted from nature, which serve as input for the manufacture of new materials and merchandise. These raw materials go through transformation processes in which value is added to finally constitute the product intended for the customer (Kauhanen, 2017). Furthermore, Machado, et al., (2016) identified that provisions are all those products that the organisation requires to consume for the manufacturing and distribution process to the final customers that are not raw material, to be previously prepared by another company. The provisions are then all the products that the company obtains from its suppliers and with which products of greater added value for the clients are obtained.

In addition, spare parts are those components and all those elements that are part of some machinery, process or property that is required for the proper functioning of the company. They are then products that are not directly involved in the process of transformation and distribution of the company, but are required for this. An example can be the spare material for a machinery, although these materials are not part of the products that the company manufactures, without these spare parts the commercial activity is slowed down and therefore not complying with the customer's request (Vieira and Loures, 2016).

There are also work in process inventory which are the products that refer to all the materials that have undergone a partial transformation process, since they are not fully elaborated with the client's specifications. The products in process are then semi-finished products that are basically made to be finished later, either because it is required to join with other components (assemble) (Dinis and Barbosa-Póvoa, 2015), it requires a different machinery or process to the one in which they are manufactured or because it is intended to finish after knowing the final customer needs, and having the semi-finished product can be delivered faster. An example of a work (or product) in process can be the partial configuration of a computer, which is developed and then completed completely, once the end customer has determined the processor or the memory capacity it requires (Teixeira, Lopes, and Figueiredo, 2018).

In addition, finished products are those elements that have been fully developed to meet customer specifications and are ready to be sent to it. It is important to keep in mind that the finished product of a particular company does not necessarily correspond to the product that the final consumer requires, since this finished product can be converted into a provision for another company (Wang and Djurdjanovic, 2018). Because the proper management of inventories requires the active participation of several departments of the company (Purchasing, manufacturing, storage, distribution, finance) (Van Houtum and Kranenburg, 2015), there is a need for good communication between these parts and inventory, so as to ensure that the materials that exist and are required for the company are correct and in the appropriate quantities. This leads to the need for adequate information systems, with which to obtain, transmit and manage information so that inventory management is efficient (Nurcahyo and Malik, 2017).

The responsibility of serving as a mattress to respond to variations in supply and demand leads companies to maintain inventories, so that the customer is satisfied. However, maintaining these inventories in the organisations presents not negligible costs, since for this activity capital investments are required in the goods (Sánchez and Sunmola, 2017), space is required to store them, personnel are needed for their administration and care and technological resources are required and energy for maintenance among others. This leads to a dilemma between maintaining a high number of inventories which satisfies the customer, but which incurs high costs (Liu, et al., 2018). According to Silva, et al., (2019), the purpose of inventory control is to ensure the operation of the company's activities by jointly optimizing the following three objectives:

- Customer service
- Inventory costs
- Operating costs

The joint optimization of these objectives means that one should not seek an improvement in any of the objectives while neglecting the others, since all three are equally important. When trying to reduce inventory costs, lower levels of materials will be incurred in the company, so the probability of customer satisfaction drops due to possible depletions; by reducing operating costs, inventory management may become insufficient, which generates inadequate information processes and long material delivery times, also affecting customer service (Cai, et al., 2017); and if the aim is to increase customer service, inventory costs and operating costs must be increased, so profitability for the company is affected. Therefore, a point should be sought in which the three objectives are met without affecting the others, which is the main function of the inventory management processes (Kontrec, et al., 2015).

Inventories are typically managed to stay in the company, however these can be found outside the company or under special care conditions, so their management is different. In addition to the types of product that are required in inventory mentioned above (Raw materials, supplies, components, product in process and finished product) it is necessary to extend this classification to other materials such as product in transit, product in consignment and inventories in quarantine (Driessen, et al., 2015).

In-transit inventories refer to all those materials that are owned by the company and that are in motion or within the distribution channels. This movement is due to the customer's request or because the company seeks to position them closer to the customer to improve the response time once the buyer requests it (Driessen, et al., 2015). It is important to take into account the inventory in transit, since only until the client receives it is part of it, then any deterioration, loss or simply mishandling that is given to them during the transport and distribution stages directly affects the costs logistics and therefore the profitability of the company (Liu, et al., 2018).

Consigned inventories refer to products that are still owned by the company and are maintained at the customers' facilities. This is done to assure the client of a high level of service, since the provisioning time of this is immediate, in that he can dispose at any time of the materials placed in his facilities. The inventories in consignment are then quantities of products that are kept in the facilities of the clients but that are still property of the company (Kontrec, et al., 2015), including, the responsibility for deterioration and the management falls to the supplier company. Consigned inventories must be managed efficiently, since these are part of the company's assets, and poor management of these generates negative impacts on the company's economy (Cai, et al., 2017).

Quarantined inventories refer to those products that require mandatory storage for a certain time, while this is adapted to the consumption conditions required by customers, such is the case of some foodstuffs or chemical products that require some time to obtain definitive characteristics of the product (Silva, et al., 2019). Quarantine inventories, although physically located in warehouses, have a special treatment, since they should not be handled to avoid confusion with the rest of the products, so that these are not available to users, which ensures that meets the required quarantine time (Sánchez and Sunmola, 2017).

The application of information technologies in inventory management has made it possible to know the availability of materials in the different locations of the logistics network, which has allowed to develop an inventory control process virtually, which seeks to make available all stocks of materials in the network, improve its allocation to meet the needs of customers, respond more efficiently to variations in demand (Nurcahyo and Malik, 2017), thereby making it possible to reach lower inventory levels and improve customer service levels. This is known as the name of virtual inventory management, which is a marked trend thanks to the development and easy implementation of information and communications technologies (ICT to the logistics and administrative processes of companies (Wang and Djurdjanovic, 2018).

Inventory of Maintenance Spare Parts

Managing the inventory involves making decisions on two fundamental aspects, on the one hand on the importance of the item and on the other on what policy to follow. The purpose of both decisions is to determine when to issue a replenishment order and how large it must be in order to comply with a restriction on customer service, or on average cost or inventory (Teixeira, Lopes, and Figueiredo, 2018). The management of spare parts inventories, although it has elements in common with the management of spare parts, introduces the characteristic that they are sent to be repaired instead of being discarded with the added complexity that they cannot always be repaired, having to be in that case replaced by a new one (Van Houtum and Kranenburg, 2015).

The first works related to the management of spare parts inventories arise from the needs of the American Navy. In a study carried out by Vieira and Loures, (2016) it is revealed that spare parts inventories represent only 7% of stored products, but on the contrary they represent 58% of the value of what is stored (initially the most valuable products are usually be designed to be repaired). According to the Dinis and Barbosa-Póvoa, (2015) the classical theory of inventory management is appropriate to manage consumables, but it is not valid to control the spare parts items that return to the Navy stores and this leads him to propose a deterministic model, based on the model EOQ (Economic Order Quantity), for spare parts inventories. This solution assumes known supply times and demand, which is received at a constant rate, does not allow deferring demand, and assumes infinite capacity by the supplier and the repair shop - with instantaneous arrivals and departures of warehouse material. The objective of the model, as in the EOQ, is to determine which are the lots that minimize the costs of possession and order for both warehouses (Dinis and Barbosa-Póvoa, 2015).

There are many works that have been developed in the field of spare parts inventories, due to their importance and complexity, as can be seen in Kauhanen, (2017). The objectives that have been pursued as well as the techniques developed are varied, given, for example, objectives such as minimization of costs, minimization of deferred demand, or minimization of total system costs subject to service restrictions. Another important aspect in the management of spare parts inventories is how demand is modelled. Although there is no consensus as to which distribution function is best suited to deal with these inventories, the most widespread way is to work with simple or compound Poisson processes.

In order to categorize the situations studied, the following characteristics related to the management model, the system or the inventories themselves can be analysed (van Jaarsveld, Dollevoet, and Dekker, 2015):

- Type of demand: Determinist or random modelled with different types of distributions
- Replenishment period: A single replenishment term or multiple terms.
- Mortality rate of inventories: It is considered or not, is deterministic or random
- Objectives pursued: Minimization of costs, minimization of stock breaks, achievement of service levels to the target customer, etc.
- Number of levels in the system: Multiple (multi echelon) or single (single echelon).

A maintenance warehouse is usually composed of spare parts, normal maintenance stocks and tools, which carry out these activities. Spare parts are those physical assets that are part of the inventories to support the company's operations. In general, they have high storage costs when they are available and their absence can generate a great impact on equipment availability costs (Wongmongkolrit, Rassameethes, and Laohakul, 2016). The problem of spare parts is in general the following:

- High unit cost.
- High achievement time.
- Slow inventory turnover.
- Consumption is random.

To solve this type of problems it is necessary to carry out an inventory management that involves:

- Control of the units installed in the plant.
- Stock control.
- Request control.
- Make historical records of consumption.
- Constant update of the list of suppliers, delivery times, price agreements, etc.

Optimization of Spare Parts Inventories

The main objective of the area of maintenance in companies, is to ensure the reliability of the assets of the organisation, an important factor in the competitiveness of the company, that is why the definition of the quantities of spare parts based on quantitative models and taking into account It counts the operational impact due to their absence, they are the main task of the inventory managers (Machado, et al., 2016). According to Suryadhini, Setiawan, and Juliani, (2019) the key elements for effective inventory optimization for an optimal level of spare parts inventories must be aligned with company policies, management systems, asset management, the process models, and the Leadership model.

Based on these criteria, it is sought to define the appropriate replacement models and the inventory management policies for spare parts that allow compliance with the strategies established for the equipment. At present, warehouses in maintenance areas have a wide variety of parts, from economical consumables used at thousands per year to critical spare parts of hundreds of thousands of dollars, which may never be used throughout the existence of the plant (Cai, Li, and Chen, 2017). According to Tang, (2017) up to 50% of the inventory value may consist of spare parts that are used at a rate of one per year or less and even, some spare parts with a value between 10% and 30% of the inventory, usually remain in a warehouse shelf throughout the life of the plant.

From a financial point of view, perhaps these spare parts should never have been purchased, however, if they had not been available when required, the company could have suffered serious economic consequences. Reliability-Centered Spare Parts (RCS) is a systematic and structured process that derives directly from the Reliability-Centered Maintenance philosophy. As such, it provides a rational basis for optimizing the inventories of critical parts.

The RCS does not take into account the recommendations of the supplier or the subjective judgment of the engineering area, but the systematic analysis of the consequences of the missing (Balcik, Bozkir, and Kundakcioglu 2016).

The great majority of the missing ones have economic effects, not having the spare when necessary costs money, either for loss of production or sales, fines, loss of product quality and other factors. In these cases, RCS uses the concept of life cycle costing to address one of the main aspects, i.e. when and how much spare parts are to be bought and maintained in the inventory (Xiao, Yang and Zhang 2015). RCS selects the quantity of spare parts that minimizes the total cost for the company. This cost includes both the purchase of spare parts, storage, inventory and financial maintenance, as well as the costs incurred if the spare part is not required when required: these are the so-called unavailability costs, which indicate how much it costs each hour waiting for the replacement, emergency purchases, freight and others (Wild 2017).

The most immediate and obvious benefit of applying RCS to critical parts is that stock levels start directly from maintenance and operations requirements. As the method is based on the analysis of the consequences, the requirements are achieved with an optimal investment in spare parts, which commonly generates a saving of between 30% and 60% of the inventory value according to Sueiro20, and achieving compliance in the production, safety and environment requirements (Singamneni et al., 2019). In general, the advantages of the RCS application are:

- Inventory reduction.
- Greater equipment availability.
- Greater plant availability.

- Elimination of "hidden stores".
- Better knowledge of the necessary resources.
- Better communication and understanding between engineering, operations and supply.
- Rational justification of decisions.
- Better understanding of the requirements of inventory and maintenance systems.
- Creation of a clearer and more beneficial relationship with suppliers.

The Management of Spare Parts in the Aviation Industry

One of the major fields of application of spare parts management is the aviation industry, where the management of spare parts is a critical element due, on the one hand to the high value of inventories and on the other, to the very high and hardly quantifiable cost of having a stationary plane, a situation known in that industry as aircraft on ground (AOG). So, by managing the spare parts, managers should try to ensure the availability of spare parts so as not to incur such a situation (Eruguz, Tan, and van Houtum, 2018).

AyuNariswari, Bamford, and Dehe, (2019) presents a decision support system that American Airlines uses to support the operations of its approximately 400 aircraft. The RAPS (Rotables Allocation and Planning System), has the demand forecasts of the spare parts and makes recommendations on the number of products to be allocated in each base. Although he does not explain the model he uses, he does mention the fact that the system incorporates the cost of cancelling a flight and that said cost is surprisingly difficult to estimate. Patriarca, et al.,

(2016) develops an analytical model that evaluates the expected number of non-operational aircraft. The model is for a single base. Model entries are stock levels as well as demand rates along with average repair and replenishment times. The model determines inventory levels that minimize the number of non-operational aircraft subject to a budget constraint. The authors conclude that the optimal allocation is practically the same as the assignment with Metric.

Gu, Zhang, and Li, 2015) deals with a case study in which they study the startup situation of a new fleet of airplanes. When a company buys a fleet of a new type of aircraft, one of the most important decisions is to determine the levels of inventories, spare parts or not, that will be needed for the operation of the fleet. In this case Davidson compares three different models to manage it. In the work of Muriel, et al., (2018), the Metric and Mod-Metric models are used to determine the target service levels, the service metric they use is the fill rate used since they modelled the demand through a Poisson distribution.

Costantino, et al., (2018) present a model to determine the stock levels of spare parts items of a commercial airline in the Philippines. The elements are characterized by an erratic demand and high cost. The system has three parts supply sources. Non-spare parts inventories are discarded and replaced by new ones. The objective is to minimize the expected annual total cost of inventory maintenance as well as aircraft delays. Recently there have been some significant contributions in the treatment of sporadic demand, as the demand for spare parts is usually categorized, in the aviation industry. Tang, (2017) analyse the reliability of the brake sub-assemblies of the Boeing 737 using a Weibull model and propose their integration with the material planning system to provide the necessary units in the planning horizon. The study analysed the causes that cause sporadic demand for spare parts in aviation. Furthermore, Suryadhini, Setiawan, and Juliani, (2019) make a comparison of 13 forecasting methods, including heuristics used by some aviation companies. For this, they apply the categorization of the demand. From both works it is concluded that the utilization rate of airplanes (flight hours, number of landings) is the factor that most influences the demand for spare parts.

Inventory Management Models

Spare inventories, as established by Wongmongkolrit, Rassameethes, and Laohakul, (2016) refers, they differ from the inventories of production or finished product, not only in their function, but in the policies that define their levels. The inventories of spare parts are supplied, stored and used, with the purpose of keeping the equipment in operational conditions; and as a product of planned and unplanned maintenance needs, and its availability responds to how the equipment is operated and maintained. Understanding the particularities of spare parts inventories, different models are found in the literature that seek to respond to the particular conditions of these inventories; Therefore, it is possible to establish the following taxonomy of existing models:

Integral Models

The integral models seek to give a global look to the spare parts, considering their interactions with the processes of the organisations, their demand and problems. In this sense, van Jaarsveld, Dollevoet, and Dekker's (2015) work gives an integral look at maintenance spare parts inventories, aligning the maintenance process with the inventory process, and concentrating its gaze on a strategy of preventive maintenance and periodic inspections for Define replacement parts. However, it neglects corrective and predictive maintenance methodologies, which are also part of the maintenance strategies, and which must be considered in a comprehensive model. The contribution of the work of Kauhanen, (2017), focuses on the optimization of orders for preventive maintenance, covering a part of the maintenance care strategy. On the other hand, in an innovative way, Dinis and Barbosa-Póvoa, (2015), address the optimization of spare parts with an approach based on risk analysis for decision making, with probability and consequence assessments applicable in the context of equipment integrity, but leaving aside aspects of monitoring the condition of the teams.

Van Houtum and Kranenburg, (2015) gives a general look at logistics and the supply chain of spare parts, with a proposed categorization of spare parts. On the other hand, the works of Wang and Djurdjanovic, (2018), propose frames of reference for spare parts, giving a general look at the study of spare parts, along with their interactions and stages in the logistics chain; however, they leave aside the clear interactions with the demand generator, maintenance, and subscribe to fundamentally logistic aspects. In the same vein, the work of Sánchez and Sunmola, (2017), develops a frame of reference for spare parts in asset-intensive companies, with the definition of segmentation, policies and forecasts of spare parts, focusing the work on aspects of control Inventory

In a more complete way, the work of Cai, et al., (2017) develops a policy for ordering and replacement of spare parts, which includes the monitoring of the condition of the equipment as input, but does not include the tactics of corrective and preventive maintenance of the equipment.

Models by Parts Segments

The models by spare parts segments seek to solve a specific problem of spare parts or a given type of spare parts. In that sense, Liu, et al., (2018) develop an applied model for parts repaired in the aeronautical industry, seeking to cover MRO planning schemes for this type of spare parts, but only giving scope to one of the spare parts segments used in maintenance. On the other hand, Driessen, et al., (2015) present an optimized model of repaired spare parts, which maximizes the availability of the equipment under a Total Volume Discount (TVBD) scheme, offered by Original Equipment Manufacturers (OEM), which also only looks at a type of spare parts and takes advantage of a sourcing strategy, which seeks a lower price by volume for the buyer. For its part, the work of Kontrec, et al., (2015), presents an optimization model, for the management of spare parts to be repaired in a service center. In the same way, they develop a model for the definition of replacement location policies from various bases that demand repaired spare parts from a central repair plant. They carry out a review exercise of the spare parts management models, both of their logistic aspects and of forecasting methods applicable to the different segments, carrying out a literature review in this regard.

Maintenance Based Models

Maintenance-based models use maintenance information to predict the behavior of spare parts. In that sense, the study by Silva, et al., (2019) proposes an approach that supports decision-making in the planning and control of spare parts in the aeronautical industry, based on a reliability model used to evaluate characteristics of the assemblies, but that falls short when not considering the maintenance tactic preventive. On the other hand, Nurcahyo and Malik, 2017) carry out a joint optimization of the planning of the operation and maintenance, with the exercise of periodic inspections to replace the parts that present failure, in a fairly complete approach to the maintenance-supply interrelation. However, it neglects strategic elements such as the definition of the maintenance tactic of the equipment, or its operational requirements, elements necessary to land the methodologies. On the other hand, the study of Teixeira, Lopes, and Figueiredo, (2018), performs a numerical study and presents a model for inventory management, depending on the maintenance policy defined for the equipment, which shows the interdependence between spare parts inventories and maintenance; however, it has flaws in terms of its integrality and the necessary management elements to ensure its effectiveness.

Models with Supply Strategy

The models that include supply strategies, seek to solve a problem of spare parts related to their logistics, optimization of their distribution or their management from supply strategies. In this field, different authors have worked models for the development of supply strategies, which is the case of Vieira and Loures, (2016) who develop a model for the location of spare parts for the Italian Air Force, seeking to minimize delays in the supply of spare parts, while seeking high availability, exploring the characteristics of a complex system, such as the supply of MRO spare parts . Similarly, Machado, et al., (2016) implement a system to share in a virtual way, with IT support, spare parts from different companies of a paper industry district in Italy, but limited to the problem of locating high-cost parts. In the field of outsourcing and its interrelation with the management of critical spare parts, the study by Cai, Li, and Chen, (2017), presents a frame of reference for decision-making in the exercise of outsourcing maintenance and management decisions of critical spare parts, given its impact on the availability of equipment.

The work of Balcik, Bozkir, and Kundakcioglu (2016) that focuses on the interaction between spare parts, safety inventories in production and maintenance, seeking the lowest long-term cost of the entire production system. Although it analyses the supply chain as a whole, it focuses on cost, and loses sight of the reliability aspects of the equipment that generates the revenue. As a summary, Annex 1 includes the review of items related to spare parts inventories. For its part, Annex 2 explains the characteristics of some of the models reviewed.

Although in recent years, spare parts inventories have been extensively studied, many of the developed inventory models focus on spare parts segments, models based on specific maintenance strategies, forecast models with sourcing strategies to determine inventory levels. orgeneral frames of reference, which limit its scope to parts of the problem of spare parts inventories. This research project proposes a comprehensive model of spare parts management, which conceptually links maintenance and supply processes, and defines both the guidelines for the segmentation of spare parts and the variables to be considered in the models of spare parts inventories.