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# Spare parts management in the aviation maintenance industry: A Literature Review

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**Abstract**

In aviation, spare parts management intends to prevent aircraft downtimes due to stockouts. It usually encompasses the forecasting of future demand for spare parts, a complex process given the probabilistic nature of failures associated with the different types of aircraft parts. To explore the methods that have been proposed in recent years to forecast aircraft spare parts demand and achieve accurate inventories in the aviation Maintenance, Repair and Overhaul (MRO) industry, this literature review aims to bring to light the results of their application. To this end, this study comprises the research, screening and contextual analysis of published studies, considering the period from 2010 to 2024. From the review of the 13 studies that resulted from the performed analysis, it was perceived that there is potential in relating aircraft maintenance demand to aircraft spare parts management.



*Keywords:* Aircraft Maintenance; Planning; Spare Parts Management; Demand Forecasting

## 1. Introduction

Spare parts management aims to ensure an inventory level in which the required spare parts are available at the required time, in the correct quantity and at the lowest possible cost [1].

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This is done to mitigate the effect of demand fluctuations [2] and avoid stockouts that cause expensive downtimes [3], which in the case of aviation are labelled with the infamous Aircraft On Ground (AOG) tag. Due to demand uncertainty, some companies maintain a large inventory [4], which leads to increased costs [5] and may result in the deterioration of parts, generating waste of material [6] and financial losses. For many aviation companies, for whom spare parts may require high investments, spare parts management tries to attain a high costumer service [7], facing the challenges of keeping the minimal required inventory [8] and achieving inventory and holding cost balance [9]. Aircraft maintenance is provided to ensure reliability, which consequently contributes to aircraft availability [10]. Preventive maintenance (PM), known in the aviation as scheduled maintenance [11], is carried out before failure occurs with the purpose of reducing the failure probability or material degradation [12]. Since this type of maintenance is deterministic by nature [13], spare parts planning is based on the direct assessment of spare parts requirements for each maintenance action. Corrective maintenance (CM), on the other hand, known in aviation as unscheduled maintenance [11], is performed only after the failure occurs, being stochastic in nature [13]. The uncertainty related to CM reduces the accuracy of the forecast, given the difficulty in predicting the required spare part types, quantities and timings. With a low demand interval, spare parts demand pattern can be classified as erratic (high demand variance) or smooth (low demand variance). On the other hand, with a high demand interval the demand pattern is classified as lumpy (high demand variance) or intermittent (low demand variance) [14]. Based on the spare parts demand pattern, different forecasting methods can be applied [15].

Aircraft spare parts demand uncertainty depending on the demand interval and variance brings more challenges to demand forecasting. Spare parts demand forecasting techniques are classified as quantitative and qualitative [16]. Examples of the former include the weighted moving average, exponentially weighted moving average and Croston's method [9], while examples of the latter include when suppliers use their own business experience [17], as well as airlines do with theirs [9]. The aircraft availability also depends on the spare parts availability [18], so it is essential to predict when these parts will be required. Spare parts demand forecasting is challenging [19] and compounded by the uncertainty of demand [20]. This study focus on how spare parts demand has been characterized, identifies spare parts management approaches and analyses how aircraft maintenance demand is considered in spare parts management. The paper is presented with an organized structure divided into five sections: introduction, methods (description of the research strategy and presentation of the questions that this study intends to answer), results (delineation of the findings presented by the selected studies), discussion (elaboration of a critical analysis of the articles and results obtained) and conclusion (a summary, where suggestions for future studies are presented to deepen the theme under analysis).

## 2. Methods

To analyze spare parts management in the aviation Maintenance, Repair and Overhaul (MRO) industry, this literature review intends to answer the following research questions:

- How is spare parts demand characterized in the aviation MRO industry?
- What are the methods used in spare parts management in the aviation MRO industry?
- How is aircraft maintenance demand considered in aircraft spare parts management?

The keywords used for the research were: "aircraft spare parts" OR "spare parts demand" OR "spare parts inventory" OR "spare parts management" AND "aviation industry" OR "aircraft industry" AND "aircraft maintenance", and the search was carried out in ScienceDirect and Taylor&Francis. This research did not use Scopus because of its extremely low inclusion rate considering the set of keywords applied. This study is intended to be extended with a broader time range and database coverage, including Web of Science, Emerald and IEEE. Concerning spare parts demand forecasting and inventory planning methods, there is no consensus on which method gives more efficient results in the aviation industry and a limited number of studies address spare parts management and maintenance demand conjointly. Since traditional methods have been frequently studied and new adapted methods have been implemented, studies published between 2010 and 2024 were included to focus on the new proposed methods. The selection process of the reviewed articles is illustrated in Figure 1.

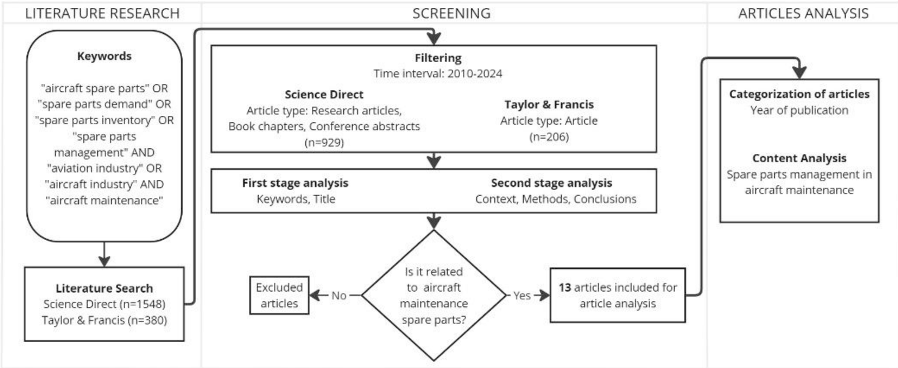


Figure 1. Literature research, screening and articles analysis

The objectives, methods and results of the 13 resulting articles are presented in Table 1.

Table 1. Articles included in this Literature Review

| Ref. | Country | Year | Objectives | Methods | Results |
|---|---|---|---|---|---|
| **[21]** | China | 2023 | Address Spare Parts Intralogistics (SPI) synchronization problems. | Demonstration case (spare parts management department at company H). The company's SPI uses delivery points to support maintenance work. Visits and interviews (7 participants: requesters, end-users and SPI teams). Implementation of Cyber-Physical Spare Parts Intralogistics System (CPSPIS). | Resource utilization is improved with CPSPIS. SPI business processes synchronization is facilitated with CPSPIS. Work efficiency can be improved given the ability of CPSPIS to synchronize business processes and resources. |
| **[22]** | Kazakhstan, France and Greece | 2021 | Test the Bootstrap method and develop a Decision Support System. | Implementation of the Bootstrap forecasting method. Test if the prediction of the Bootstrap method corresponds to real demand, given selected lead times. Regression analysis. Development of a Decision Support System so that maintenance personnel can obtain relevant information. | For spare parts with intermittent demand pattern, the Bootstrap method showed very accurate results. For spare parts with lumpy demand, the Bootstrap method results were not as highly accurate as with spare parts with intermittent demand pattern. |
| **[23]** | Jordan | 2020 | Set an inventory management system. Improve operational availability. | Inventory Management System customization.<br>Integration of Maintenance Management Systems. | Demonstrated that Inventory Management Systems can be developed for maintenance of systems. The I.M.S. program increases inventory management system's efficiency, forecasts for distinct time lengths and reduces cases of Aircraft on Ground, being useful to calculate inventory quantity needs and to highlight deficiency of materials. The proposed system may lead to cost savings. |
| **[24]** | Belgium and the Netherlands | 2019 | Create a forecasting mechanism to estimate the distribution of spare parts demand. Develop an inventory control method. | Data analysis (data from Fokker Services and Netherlands Railways).<br>Comparative evaluation between the proposed approach and benchmarks.<br>Use of maintenance information as a source of Advance Demand Information (ADI) for spare parts inventory control. | Obtaining in advance the maintenance plan can lead to cost savings. The ADI-based forecast showed better results than time series methods concerning forecast accuracy. ADI presented advantages in Root Mean Square Error and Mean Absolute Deviation. The proposed approach avoids redundant inventory and has the potential to reduce costs by 23% (train maintenance) to 51% (aircraft maintenance). |
| **[25]** | Portugal | 2019 | Suggest a Framework for Aircraft Maintenance Estimation (FRAME). | Application of a 3-Dimensional Maintenance Data Analysis method. Use of maintenance estimation indicators to assess expected maintenance potential impact (e.g., spare parts quantity). Quantitative assessment of aircraft maintenance projects from a Portuguese Maintenance, Repair and Overhaul (MRO). | FRAME addresses spare parts management problem by integrating maintenance activities planning/scheduling and resources availability (e.g., spare parts). Unscheduled maintenance work can be 198% of scheduled workload. Throughout the duration of the service life of an aircraft, there is an increase of the ratio between unscheduled and scheduled workloads. |

Table 1. (continued)

| Ref. | Country | Year | Objectives | Methods | Results |
|---|---|---|---|---|---|
| [26] | Indonesia and UK | 2019 | Maintain aircraft operational availability and reduce downtime. | Develop a multi-criteria model for aircraft spare parts based on 9 interviews (3 from airlines, 3 from engineering and maintenance department and 3 from the material department). Classification test. Data analysis (1267 part numbers). Comparison between the Analytical Hierarchy Process (AHP) model and current practice (Mathematical model, Mathematical and Engineering adjustment) and Current Inventory. | Considering the MRO dependency on spare parts availability, the proposed AHP model leads to a practical aircraft spare parts classification, by aggregating qualitative and quantitative criteria. AHP classification accuracy is high, since its outcome is consistent with current precise methods. AHP vs Math Model: 80.6% similarity. AHP vs Math Model and Engineering Adjustment Method: 97.6% similarity. AHP vs Current inventory: 63.7% similarity. |
| [27] | Italy | 2017 | Inventory allocation optimization for spare parts with irregular demand. | Presentation of METRIC. Single-site model analysis where a machine may represent an aircraft (possible scenario representation of a maintenance outsourcing service). Proposal and application of Zero-Inflated Poisson and Multi Echelon Technique for Recoverable Item Control (ZIP-METRIC). Data analysis (1745 items of an airline). Simulation study. Item classification for ZIP-METRIC and METRIC. | METRIC-like models may present accuracy limitations for high irregular demand. ZIP-METRIC defines an inventory level closer to a real case when compared to METRIC. ZIP-METRIC presents better performance compared to the traditional Poisson-based approach. |
| [28] | The Netherlands | 2017 | Propose (for spare parts) a Lead Time Demand forecasting method. | Development of the empirical Extreme Value Theory method as a combination of the non-parametric empirical method and empirical Extreme Value extrapolation. Simulation study (CM demand only or combined with PM demand). Empirical study (automotive case and aircraft case). | Simulation results indicated that the empirical Extreme Value Theory method performs relatively well but presents some challenges when there is limited demand history. When compared to the empirical method, the proposed method improves inventory performance. |
| [29] | China | 2016 | Present an approach for spare parts ordering. | Analysis of policies for spare parts and demand ordering decisions (new aircraft fleet). Failure time and number prediction. Classical and Bayesian methods results analysis. Analysis of data (supplier) and maintenance records (airlines). | Bayesian prediction outcomes were more accurate (by including testing and historical data). Fleet size and the length of the prediction interval affect spare parts demand rate. |
| [30] | The Netherlands | 2015 | Support inventory analysts. | Development of a model and an algorithm for inventory support. Computational analysis. Implementation of a spare parts algorithm in a decision-support system at a repair shop (Fokker Services). Comparison results analysis between the implemented method and a benchmark method. | Repair shop performance must be measured not on spare parts level, but on component repair level. The benchmark method was unable to achieve the intended performance for 52% of the highly critical components and showed costs 33% higher. Inventory control improvement with the implementation of the method at the repair shop. |
| [31] | Canada | 2014 | Create a spare parts inventory model. Reduce downtime and high inventory holding cost. | Presentation of a basic model and development of an improved model. Results analysis for iterative (basic model) and general algebraic modeling system approaches (basic model and improved model). Numerical examples. Sensitivity analysis on how the optimal solution is affected. Comparison of models (basic vs improved). | Computational results show that inventory cost can be significantly reduced with the proposed basic model. Compared to traditional methods, the proposed mathematical models may be more appropriate because they take into account parts aging and have their focus on impending demands. |
| [32] | Canada | 2014 | Address spare parts logistics (third-party maintenance provider). | Development of models: deterministic and stochastic. Numerical experiments. Comparison between the multi-stage stochastic programming model, the mean-value deterministic model and a robust optimization (deterministic worst-case scenario) model. | It was concluded that the spare parts inventory plan must be coordinated with maintenance operations. The robust optimization model suggested higher costs. The deterministic model lacks efficiency on spare parts order quantity. MSP model performed better compared to mean-value deterministic and robust optimization models. |

Table 1. (continued)

| Ref. | Country | Year | Objectives | Methods | Results |
|---|---|---|---|---|---|
| **[33]** | The Netherlands | 2012 | Propose a method that considers spare parts demand and what type of component is repaired. | Data analysis (Fokker Services). Consideration of 3 spare parts categories (very-slow, slow and fast moving). Studied methods: Two-Step (2S), Simple Exponential Smoothing (ES), Moving Average (MA), Croston (CR), Syntetos-Boylan Approximation (SBA), Teunter-Syntetos-Babai (TSB), Zero Forecast (ZF) and Naïve Forecast (NF). Comparative study (forecasting methods results). Simulation study (2S and ES). | By using information from planned maintenance and repairs, 2S may reduce forecasting errors by up to 20%. 2S helps distinguish changes on demand: component demand vs needs for parts per repair. In the empirical study, 2S did not outperform ES. The performance measure (Root Mean Square Error, Mean Absolute Deviation and Mean Error) showed that for very-slow and slow-moving spare parts, 2S produced close results to ES, MA and TSB and outperformed CR. For fast moving spare parts, 2S, ES, MA, CR, SBA and TSB produced close results. |

## 3. Results

The results of this literature review are presented and organized in order to specify the parameters that were considered relevant for this study. Thus, the organization of the results obtained in this work includes for each study: i) the reference, ii) country, iii) year of publication, iv) objectives, v) methods applied and developed to meet the proposed objectives and vi) results. The methods classification according to their objectives and focus is summarized in Figure 2. Therefore, the conclusions of this work answer the proposed research questions regarding the spare parts management in the maintenance aviation industry.

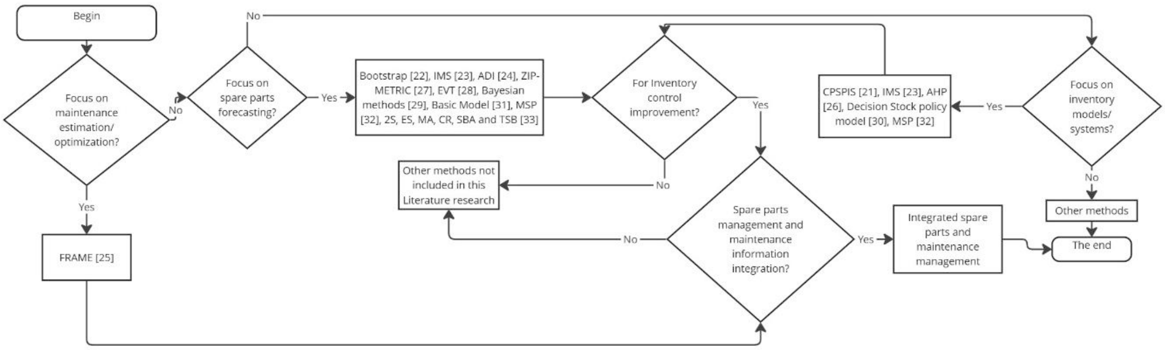


Figure 2. Methods classification according to their objectives and focus

### *3.1 Characterization of spare parts demand in the aviation MRO industry*

Depending on the driving cause of spare parts demand (scheduled or unscheduled maintenance), spare parts management may be based on known requirements or demand forecasts. By presenting a stochastic nature, CM requires the use of forecasting techniques. CM is mainly triggered by sudden component or system failure. This uncertainty is also related to different distribution of maintenance tasks [24] and a high number of aircraft components subject to potential failure [32]. Thus answering the first research question, according to the perceptions or references to relevant literature presented by the studies included in this review, spare parts demand in the aviation industry is mostly characterized as intermittent [22], [25], [26], [29], [33], erratic [29] or lumpy [22], [25], [29], [33].

### *3.2 Methods used in spare parts management in the aviation MRO industry*

There are distinct methods that have been used in aircraft spare parts management. These methods have been frequently compared to the traditional methods for performance analysis. The second research question is answered by compiling the methods presented by the selected studies and their benefits. The 2S forecasting method is able to use information from scheduled maintenance and repairs which could lead to a reduction of the forecasting errors. For the very-slow and slow moving spare parts categories, 2S outperforms CR [33]. The Bootstrap method presents accurate results for intermittent demand patterns [22]. For spare parts forecasting, the application of a method that combines the non-parametric empirical method with the extreme value theory extrapolation is also used, as the empirical Extreme Value Theory (EVT) method performs relatively well [28]. To handle spare parts demand intermittency and lumpiness, using planned maintenance as Advance Demand Information can have a potential impact in reducing the companies costs [24]. To get a forecast demand value for a certain service level, decision-support systems such as the one developed in [22] help materials managers when using Bootstrap forecasting method. In the context of the establishment of aircraft fleets, Bayesian prediction by integrating historical and testing data [29] produces more accurate results. For inventory optimization models that are able to incorporate operator requirements as time-window fill requirements (concerning each repair time of each different type of component) may be used [30]. For inventory level definition, the ZIP-METRIC method shows better outcomes when compared to METRIC [27]. From a third-party provider perspective, when the aim is to protect the spare parts inventory from shortage, some preventive measures can be taken, such as predicting a high demand of parts, although it could translate into an increase of expenses. Comparing to robust worst-case scenario and mean value deterministic models, using multi-stage stochastic programming models may lead to better outcomes [32]. In addition, spare parts classification systems may help secure operational availability, like AHP models [26]. Spare parts, when used as maintenance estimation indicators, can help better perceive expected maintenance impact [25]. In inventory management contexts, models that consider parts aging may be appropriate approaches [31]. Computer-based inventory management systems, such as Inventory Management System [23], are also used.

### *3.3 Spare parts management and maintenance demand*

Spare parts demand and maintenance demand are commonly addressed separately [25]. Some studies suggest that the information resulting from maintenance work must be considered in spare parts management [24], [33]. To answer the third research question, we argue that there are indications that spare parts planning should be linked to maintenance [32]. Spare parts inventory planning relates to aircraft maintenance through an exchange of information. Not only the information regarding maintenance must be integrated with spare parts management, but also the type of maintenance (On Condition maintenance tasks are considered important drivers of spare parts demand [24]) and due dates, such as in the case of third-party providers [32]. An accurate prediction of the required spare parts quantities for unexpected maintenance is critical [22]. The integration of information concerning maintenance can be obtained with the ADI approach [24], facilitating inventory control and cost reduction. The link between spare parts availability and maintenance demand can also be achieved with FRAME [25], as well the relevant information regarding scheduled maintenance can be integrated through the application of the 2S method [33]. Another aspect of maintenance and parts demand is the life cycle of the parts and how that cycle may affect parts availability. Keeping materials in good condition is a decisive factor in all industries, especially in the case of the aviation industry. Thus, the adopted methods and models may benefit from considering parts aging and impending demands. Non-linear programming models may be implemented to forecast impending demand based on the failure distribution of installed parts [31]. A multi-criteria classification can be used for spare parts inventory management [26]. Cyber-Physical Intralogistics system can serve maintenance logistics and it may be implemented to increase decision-support capacity [21], helping companies reach an efficient intralogistics collaboration and management in a MRO context.

## 4. Discussion

The following subsections discuss the topics for the purpose of analyzing the articles included in this study: spare parts demand forecasting challenges, methods used in spare parts management in the aviation industry, spare parts management and maintenance demand.

### *4.1 Spare parts demand forecasting challenges*

Forecasting is crucial in supply chain planning [34] and it is essential to forecast the use of aircraft spare parts [35] in order to make resource decisions in articulation with the quantities needed. As a result of the uncertain nature of demand (especially in the context of CM), the forecast of the optimal quantity to order or to be kept in inventory is based on methods that cannot always match the actual unexpected needs. Given the large amount of spare parts existing in the supply chain [36], demand forecasting can be linked to high costs. Another challenge can be the existence of forecasting methods with forecast data that is not consistent with the actual quantities of parts used [17], which adds to the fact that some of these methods are insufficient to obtain quantity and intervals forecasting in the context of non-smooth demand [2]. The lumpiness of the demand consequently causes challenges [37] and affects inventory planning. There are systems that avoid errors inherent when certain demand forecasting methods are applied to demand with intermittent behavior [38]. For some industries, spare parts forecasting may be challenging [39] and demand size is subject to variation [40]. Thus, spare parts demand behavior must be considered, as well as the existence of sudden peaks in demand. Time series methods are based on historical data and may be unable to forecast those sudden peaks [24]. Combined with the variable nature of spare parts demand, the limited number of studies conducted that use maintenance data to estimate demand also makes it difficult to understand the real impact of maintenance needs for spare parts. Thereby an analysis of the primary factors contributing to the irregularity in demand may lead to more accurate predictions of spare parts demand. The studies included in this literature review concerning the causes of intermittency pointed to maintenance tasks unbalanced distribution [24]. Concerning the causes of lumpiness, there are studies that refer failure mode and fleet size [41]. Addressing these causes may provide relevant insight on spare parts demand analysis. Furthermore, the forecasting of spare parts is difficult due not only to the uncertainty of demand but with external suppliers there is also the uncertainty concerning the lead time [32], as well as the uncertainty concerning the life cycle phase of the spare part. For instance, the end-of-life phase presents a challenging and expensive supply chain management [42]. Besides, equipment re-design (when a system is modified) have direct consequences on required spare parts as it can change the optimal number: some of the spare parts may become redundant [43] (leading to excessive inventory) or more spare parts may be required (leading to insufficient inventory). Studies suggest that companies benefit from having the ability to face the increase of maintenance demand and may resort to Genetic Algorithms to generate aircraft maintenance schedules that are necessary to spare parts planning [44]. Simulation based optimization approaches are also used in a military context, specifically to spare parts forecasting [37], since military equipment may have periods with a high rate of use interspersed with periods of inactivity which makes it difficult to predict the demand for spare parts.

### *4.2 Methods used in spare parts management in the maintenance aviation industry*

In spare parts management different forecasting methods are used, including MA, ES, CR, SBA, TSB, ZF and NF [33]. However, some of these forecasting methods do not consider repair processes even though they are considered one of the causes for the intermittency and lumpiness of demand [33]. Not all methods can be used for certain demand distributions (e.g. ZF does not cope with a zero mean and a variance with positive values), thus taking conclusions regarding the effect that the application of those methods has on inventory control parameters may be preferable for slow-moving items [45]. Concerning spare parts demand forecasting, time series forecasting methods present a reactive behavior to new factors and are often unable to predict sudden increases in demand (i.e., peaks) [24]. Spare parts demand may present periods when it is non-existent. The use of some traditional methods (e.g. ES and MA [46]) may not be recommended for periods with zero demand, requiring spare parts management to use different methods. CR deals with the demand intermittency by updating the demand size and occurrence interval when there is a period with positive demand [33], [47]. However, CR may present some limitations [47]. TSB has the ability to deal with obsolescence and SBA deflates CR forecast to address CR limitations [33]. The existence of different maintenance activities (inspection, monitoring, routine maintenance, overhaul, rebuilding and repair [43]) requires distinct spare parts. Forecast error reduction can be achieved by 2S using planned maintenance and repair operations information [33]. Spare parts forecasting can benefit from real-time condition monitoring [48] so a dynamic control of the spare parts inventory can be valuable, even helping decrease costs. Structured shared information may benefit inventory management [24]. The adaptation of a Genetic Algorithm to create robust maintenance scheduling may result in a potential reduction in costs associated with maintenance. It can also impact on spare parts management since airlines use long-term maintenance schedules information to address future needs (e.g. spare parts) [44]. Some existing methods used on the spare parts inventory optimization are unable to ensure performance on a component level, so automated methods that are able to determine (s,S) policies and deal with large quantities of spare parts produce promising results concerning inventory control at component repair shops [30]. The use of different methods for similar contexts is noticeable, which reflects the lack of a spare parts management method established and indisputably considered as the most reliable in the maintenance aviation industry.

### *4.3 Spare parts management and maintenance demand*

Spare parts management plays a critical role in maintenance, being maintenance performance affected by it [21]. Maintenance is essential to guarantee operational safety [49] and availability. Spare parts inventories serve maintenance planning [31], being crucial in the maintenance of inoperative aircrafts [50]. Maintenance may not result in spare parts demand, but spare parts are only required when maintenance occur [23]. Planning for future needs is considered essential for airlines [51]. Given the direct consequences that efficient planning has on a company's costs and operational availability, accurate spare parts management is of the utmost importance. Spare parts demand is often addressed without considering the demand for maintenance [25]. For industries, the execution of maintenance can be hindered by the way in which that inventories are managed [52], existing a trade-off between preventing downtime (suitable redundancy level) and system restoration (suitable spare parts inventory) [53]. An analysis of maintenance demand can offer these industries relevant information to spare parts management. Furthermore, new management strategies are conditioned by the associated costs [54] and companies have a budget that can be impacted by the sudden demand for spare parts. In the context of AOG, companies encounter elevated costs related to acquisitions from external suppliers, which can have an impact on the company's budget [22] and result in adding more uncertainty to the spare parts planning due to lead time and capacity [32]. The level of aircraft availability depends on different factors, one of them being the spare parts availability [55].

Spare parts need to be available when required [56]. Studies highlight the importance of integrating information on spare parts orders. By integrating this information, industries may obtain a more detailed maintenance organization, as well as an accurate replenishment of parts [57]. In the aviation maintenance industry, making spare parts available for maintenance is essential for airlines to have operational aircraft. Compliance with airworthiness requirements is ensured through data traceability [58], which demonstrates the importance of data integration. Setting the spare parts that are considered to be needed is also done by using information deriving from maintenance schedules [44]. The integration of maintenance information is not only essential to spare parts management, but studies suggest that it may also reduce costs [24]. To work effectively, MRO requires spare parts to be managed in such a way as to meet their real needs. Some machine learning algorithms have been studied to optimize spare parts supply, being Random Forest the one who presented better results against Decision Tree and Support Vector Machine in one study [59].

## 5. Conclusion

The purpose of this literature review is to study the spare parts management in the aviation MRO sector. Spare parts demand in the aviation industry is often characterized by irregularity, intermittency and lumpiness, these being contributing factors to the difficulty presented in obtaining accurate demand forecasts. Traditional forecasting methods continue to serve the purpose of estimating inventory requirements, yet they present limitations. These methods can be adapted, avoiding unnecessary costs and aiming for a higher service level. The continuous use of different forecasting methods and inventory models for the same purpose demonstrates the absence of a consensus regarding which forecasting method and inventory model are the most accurate for spare parts management. Articulating information between spare parts management and aircraft maintenance is essential to achieve an improved inventory planning. There are still some lacunae in the existing literature regarding them conjointly and conclusively defining which methods using maintenance demand information are the most accurate for spare parts management. This literature review intended to fill a research gap in accounting spare parts management relation with maintenance, by identifying the existing spare parts management methods that consider maintenance demand and offering a relevant overview on this topic. Although a comprehensive interval has been considered (2010-2024), a growing trend of publications is noticeable concerning spare parts management and maintenance demand. The main limitation of this literature review was the scope of all the studies, conditioned by database selection. This limitation was mitigated by systematic search strategies with significant coverage of current relevant studies that answered the proposed research questions. Future studies should deepen the potential relation between spare parts management and maintenance demand. A comprehensive analysis of how aircraft maintenance demand is considered in aircraft spare parts management would support companies to achieve a more efficient spare parts management function and increase their level of service.

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## References


[1] A. E. Haroun and S. O. Duffuaa, “Maintenance Organization,” in *Handbook of Maintenance Management and Engineering*, M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, and D. Ait-Kadi, Eds., London: Springer London, 2009, pp. 3–15. doi: 10.1007/978-1-84882-472-0_1.

[2] M. Şahin, F. Eldemir, and A. Turkyilmaz, “Inventory Cost Minimization of Spare Parts in Aviation Industry,” *Transp. Res. Procedia*, vol. 59, pp. 29–37, 2021, doi: 10.1016/j.trpro.2021.11.094.

[3] P. Dendauw, T. Goeman, D. Claeys, K. D. Turck, D. Fiems, and H. Bruneel, “Condition-based critical level policy for spare parts inventory management,” *Comput. Ind. Eng.*, vol. 157, p. 107369, Jul. 2021, doi: 10.1016/j.cie.2021.107369.

[4] Y. Hafner, J. Bock, C. Keppler, and J. Fottner, “Evaluation model for cooperative inventory pooling-systems,” *Procedia CIRP*, vol. 104, pp. 253–258, 2021, doi: 10.1016/j.procir.2021.11.043.

[5] V. P. Singh and K. K. Ganguly, “A supporting framework for estimating trade-off between cost and availability at equipment level: development and application in the aircraft MRO industry,” *Prod. Plan. Control*, vol. 35, no. 8, pp. 808–823, Jun. 2024, doi: 10.1080/09537287.2022.2136549.

[6] M. Ruan, Y. Luo, and H. Li, “Configuration model of partial repairable spares under batch ordering policy based on inventory state,” *Chin. J. Aeronaut.*, vol. 27, no. 3, pp. 558–567, Jun. 2014, doi: 10.1016/j.cja.2014.04.021.

[7] E. Cakmak and E. Guney, “Spare parts inventory classification using Neutrosophic Fuzzy EDAS method in the aviation industry,” *Expert Syst. Appl.*, vol. 224, p. 120008, Aug. 2023, doi: 10.1016/j.eswa.2023.120008.

[8] V. F. Yu, N. Y. Salsabila, N. Siswanto, and P.-H. Kuo, “A two-stage Genetic Algorithm for joint coordination of spare parts inventory and planned maintenance under uncertain failures,” *Appl. Soft Comput.*, vol. 130, p. 109705, Nov. 2022, doi: 10.1016/j.asoc.2022.109705.

[9] A. Regattieri, M. Gamberi, R. Gamberini, and R. Manzini, “Managing lumpy demand for aircraft spare parts,” *J. Air Transp. Manag.*, vol. 11, no. 6, pp. 426–431, Nov. 2005, doi: 10.1016/j.jairtraman.2005.06.003.

[10] H. Kinnison and T. Siddiqui, *Aviation Maintenance Management, Second Edition*, 2nd ed. New York, N.Y: McGraw-Hill Education, 2013.

[11] D. Dinis, A. Barbosa-Póvoa, and Â. P. Teixeira, “Valuing data in aircraft maintenance through big data analytics: A probabilistic approach for capacity planning using Bayesian networks,” *Comput. Ind. Eng.*, vol. 128, pp. 920–936, Feb. 2019, doi: 10.1016/j.cie.2018.10.015.

[12] A. C. Márquez, *The Maintenance Management Framework: Models and Methods for Complex Systems Maintenance*. in Springer Series in Reliability Engineering. London: Springer London, 2007. doi: 10.1007/978-1-84628-821-0.

[13] M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, and D. Ait-Kadi, Eds., *Handbook of Maintenance Management and Engineering*. London: Springer London, 2009. doi: 10.1007/978-1-84882-472-0.

[14] A. A. Syntetos, J. E. Boylan, and J. D. Croston, “On the categorization of demand patterns,” *J. Oper. Res. Soc.*, vol. 56, no. 5, pp. 495–503, May 2005, doi: 10.1057/palgrave.jors.2601841.

[15] C. Diallo, D. Ait-Kadi, and A. Chelbi, “Integrated Spare Parts Management,” in *Handbook of Maintenance Management and Engineering*, M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, and D. Ait-Kadi, Eds., London: Springer London, 2009, pp. 191–222. doi: 10.1007/978-1-84882-472-0_9.

[16] Y. Yang, W. Liu, T. Zeng, L. Guo, Y. Qin, and X. Wang, “An Improved Stacking Model for Equipment Spare Parts Demand Forecasting Based on Scenario Analysis,” *Sci. Program.*, vol. 2022, pp. 1–15, Jun. 2022, doi: 10.1155/2022/5415702.

[17] F. Guo, J. Diao, Q. Zhao, D. Wang, and Q. Sun, “A double-level combination approach for demand forecasting of repairable airplane spare parts based on turnover data,” *Comput. Ind. Eng.*, vol. 110, pp. 92–108, Aug. 2017, doi: 10.1016/j.cie.2017.05.002.

[18] H. Ren, X. Chen, and Y. Chen, “Chapter 2 - Basic Concepts,” in *Reliability Based Aircraft Maintenance Optimization and Applications*, H. Ren, X. Chen, and Y. Chen, Eds., Academic Press, 2017, pp. 19–36. doi: 10.1016/B978-0-12-812668-4.00002-2.

[19] T. B. Affonso, S. V. Conceição, L. R. Muniz, J. F. De Freitas Almeida, and J. C. De Lima, “A new hybrid forecasting method for spare part inventory management using heuristics and bootstrapping,” *Decis. Anal. J.*, vol. 10, p. 100415, Mar. 2024, doi: 10.1016/j.dajour.2024.100415.

[20] H. Rezaei, A. Baboli, M. K. Shahzad, and R. Tonadre, “A new methodology to optimize target stock level for unpredictable demand of spare parts: A Case Study in Business Aircrafts’ Industry,” *IFAC-Pap.*, vol. 51, no. 11, pp. 538–543, 2018, doi: 10.1016/j.ifacol.2018.08.374.

[21] Q. Chen, M. Li, G. Xu, and G. Q. Huang, “Cyber-physical spare parts intralogistics system for aviation MRO,” *Adv. Eng. Inform.*, vol. 56, p. 101919, Apr. 2023, doi: 10.1016/j.aei.2023.101919.

[22] M. Baisariyev *et al.*, “Demand forecasting methods for spare parts logistics for aviation: a real-world implementation of the Bootstrap method,” *Procedia Manuf.*, vol. 55, pp. 500–506, 2021, doi: 10.1016/j.promfg.2021.10.068.

[23] H. Al-Momani, O. T. Al Meanazel, E. Kwaldeh, A. Alaween, A. Khasaleh, and A. Qamar, “The efficiency of using a tailored inventory management system in the military aviation industry,” *Heliyon*, vol. 6, no. 7, p. e04424, Jul. 2020, doi: 10.1016/j.heliyon.2020.e04424.

[24] S. Zhu, W. V. Jaarsveld, and R. Dekker, “Spare parts inventory control based on maintenance planning,” *Reliab. Eng. Syst. Saf.*, vol. 193, p. 106600, Jan. 2020, doi: 10.1016/j.ress.2019.106600.

[25] D. Dinis, A. Barbosa-Póvoa, and Â. P. Teixeira, “A supporting framework for maintenance capacity planning and scheduling: Development and application in the aircraft MRO industry,” *Int. J. Prod. Econ.*, vol. 218, pp. 1–15, Dec. 2019, doi: 10.1016/j.ijpe.2019.04.029.

[26] N. P. Ayu Nariswari, D. Bamford, and B. Dehe, “Testing an AHP model for aircraft spare parts,” *Prod. Plan. Control*, vol. 30, no. 4, pp. 329–344, Mar. 2019, doi: 10.1080/09537287.2018.1555341.

[27] F. Costantino, G. Di Gravio, R. Patriarca, and L. Petrella, “Spare parts management for irregular demand items,” *Omega*, vol. 81, pp. 57–66, Dec. 2018, doi: 10.1016/j.omega.2017.09.009.

[28] S. Zhu, R. Dekker, W. Van Jaarsveld, R. W. Renjie, and A. J. Koning, “An improved method for forecasting spare parts demand using extreme value theory,” *Eur. J. Oper. Res.*, vol. 261, no. 1, pp. 169–181, Aug. 2017, doi: 10.1016/j.ejor.2017.01.053.

[29] S. Yongquan, C. Xi, R. He, J. Yingchao, and L. Quanwu, "Ordering decision-making methods on spare parts for a new aircraft fleet based on a two-sample prediction," *Reliab. Eng. Syst. Saf.*, vol. 156, pp. 40–50, Dec. 2016, doi: 10.1016/j.ress.2016.07.017.

[30] W. Van Jaarsveld, T. Dollevoet, and R. Dekker, "Improving spare parts inventory control at a repair shop," *Omega*, vol. 57, pp. 217–229, Dec. 2015, doi: 10.1016/j.omega.2015.05.002.

[31] J. Gu, G. Zhang, and K. W. Li, "Efficient aircraft spare parts inventory management under demand uncertainty," *J. Air Transp. Manag.*, vol. 42, pp. 101–109, Jan. 2015, doi: 10.1016/j.jairtraman.2014.09.006.

[32] M. Kazemi Zanjani and M. Nourelfath, "Integrated spare parts logistics and operations planning for maintenance service providers," *Int. J. Prod. Econ.*, vol. 158, pp. 44–53, Dec. 2014, doi: 10.1016/j.ijpe.2014.07.012.

[33] W. Romeijnders, R. Teunter, and W. Van Jaarsveld, "A two-step method for forecasting spare parts demand using information on component repairs," *Eur. J. Oper. Res.*, vol. 220, no. 2, pp. 386–393, Jul. 2012, doi: 10.1016/j.ejor.2012.01.019.

[34] Y. Wang, X. Wang, and A. Liu, "Digital Twin-driven Supply Chain Planning," *Procedia CIRP*, vol. 93, pp. 198–203, 2020, doi: 10.1016/j.procir.2020.04.154.

[35] Y. Yang, L. Sun, and C. Guo, "Aero-Material Consumption Prediction Based on Linear Regression Model," *Procedia Comput. Sci.*, vol. 131, pp. 825–831, 2018, doi: 10.1016/j.procs.2018.04.271.

[36] N. A. Mobarakeh, M. K. Shahzad, A. Baboli, and R. Tonadre, "Improved Forecasts for uncertain and unpredictable Spare Parts Demand in Business Aircraft's with Bootstrap Method," *IFAC-Pap.*, vol. 50, no. 1, pp. 15241–15246, Jul. 2017, doi: 10.1016/j.ifacol.2017.08.2379.

[37] P. Sharma, M. S. Kulkarni, and V. Yadav, "A simulation based optimization approach for spare parts forecasting and selective maintenance," *Reliab. Eng. Syst. Saf.*, vol. 168, pp. 274–289, Dec. 2017, doi: 10.1016/j.ress.2017.05.013.

[38] J. D. Croston, "Forecasting and Stock Control for Intermittent Demands," *Oper. Res. Q. 1970-1977*, vol. 23, no. 3, pp. 289–303, 1972, doi: 10.2307/3007885.

[39] M. Z. Babai, H. Chen, A. A. Syntetos, and D. Lengu, "A compound-Poisson Bayesian approach for spare parts inventory forecasting," *Int. J. Prod. Econ.*, vol. 232, p. 107954, Feb. 2021, doi: 10.1016/j.ijpe.2020.107954.

[40] W. Wang and A. A. Syntetos, "Spare parts demand: Linking forecasting to equipment maintenance," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 47, no. 6, pp. 1194–1209, Nov. 2011, doi: 10.1016/j.tre.2011.04.008.

[41] A. F. Lowas and F. W. Ciarallo, "Reliability and operations: Keys to lumpy aircraft spare parts demands," *J. Air Transp. Manag.*, vol. 50, pp. 30–40, Jan. 2016, doi: 10.1016/j.jairtraman.2015.09.004.

[42] M. Hur, B. B. Keskin, and C. P. Schmidt, "End-of-life inventory control of aircraft spare parts under performance based logistics," *Int. J. Prod. Econ.*, vol. 204, pp. 186–203, Oct. 2018, doi: 10.1016/j.ijpe.2018.07.028.

[43] A. C. Márquez, *The Maintenance Management Framework: Models and Methods for Complex Systems Maintenance*. in Springer Series in Reliability Engineering. London: Springer London, 2007. doi: 10.1007/978-1-84628-821-0.

[44] T. V. D. Weide, Q. Deng, and B. F. Santos, "Robust long-term aircraft heavy maintenance check scheduling optimization under uncertainty," *Comput. Oper. Res.*, vol. 141, p. 105667, May 2022, doi: 10.1016/j.cor.2021.105667.

[45] R. H. Teunter and L. Duncan, "Forecasting intermittent demand: a comparative study," *J. Oper. Res. Soc.*, vol. 60, no. 3, pp. 321–329, Mar. 2009, doi: 10.1057/palgrave.jors.2602569.

[46] E. Van Wingerden, R. J. I. Basten, R. Dekker, and W. D. Rustenburg, "More grip on inventory control through improved forecasting: A comparative study at three companies," *Int. J. Prod. Econ.*, vol. 157, pp. 220–237, Nov. 2014, doi: 10.1016/j.ijpe.2014.08.018.

[47] A. A. Syntetos and J. E. Boylan, "On the bias of intermittent demand estimates," *Int. J. Prod. Econ.*, vol. 71, no. 1–3, pp. 457–466, May 2001, doi: 10.1016/S0925-5273(00)00143-2.

[48] S. Keivanpour and D. A. Kadi, "The Effect of 'Internet of Things' on Aircraft Spare Parts Inventory Management," *IFAC-Pap.*, vol. 52, no. 13, pp. 2343–2347, 2019, doi: 10.1016/j.ifacol.2019.11.556.

[49] I. De Pater and M. Mitici, "Predictive maintenance for multi-component systems of repairables with Remaining-Useful-Life prognostics and a limited stock of spare components," *Reliab. Eng. Syst. Saf.*, vol. 214, p. 107761, Oct. 2021, doi: 10.1016/j.ress.2021.107761.

[50] J. Sheng and D. Prescott, "Optimising spare parts provision and inspection intervals for an aircraft fleet undergoing cannibalisation," *Saf. Reliab.*, vol. 36, no. 2, pp. 88–105, Apr. 2016, doi: 10.1080/09617353.2016.1219935.

[51] Z. Kenzhevayeva, A. Katayeva, K. Kaikenova, A. Sarsembayeva, M.Z. Babai, M. Tsakalerou and C.T. Papadopoulos, "Inventory control models for spare parts in aviation logistics," *FAIM 2021*, vol. 55, pp. 507–512, Jan. 2021, doi: 10.1016/j.promfg.2021.10.069.

[52] P. Bülbül, Z. P. Bayındır, and İ. S. Bakal, "Exact and heuristic approaches for joint maintenance and spare parts planning," *Comput. Ind. Eng.*, vol. 129, pp. 239–250, Mar. 2019, doi: 10.1016/j.cie.2019.01.032.

[53] A. Sleptchenko and M. Van Der Heijden, "Joint optimization of redundancy level and spare part inventories," *Reliab. Eng. Syst. Saf.*, vol. 153, pp. 64–74, Sep. 2016, doi: 10.1016/j.ress.2016.04.006.

[54] G. Cardeal, M. Leite, and I. Ribeiro, "Decision-support model to select spare parts suitable for additive manufacturing," *Comput. Ind.*, vol. 144, p. 103798, Jan. 2023, doi: 10.1016/j.compind.2022.103798.

[55] H. Ren, X. Chen, and Y. Chen, *Reliability based aircraft maintenance optimization and applications*. in Shanghai Jiao Tong University press aerospace series. San Diego: Academic press, 2017.

[56] T. S. Vaughan, "Failure replacement and preventive maintenance spare parts ordering policy," *Eur. J. Oper. Res.*, vol. 161, no. 1, pp. 183–190, Feb. 2005, doi: 10.1016/j.ejor.2003.06.026.

[57] W. Zhang, S. He, X. Zhang, and X. Zhao, "Joint optimization of job scheduling, condition-based maintenance planning, and spare parts ordering for degrading production systems," *Reliab. Eng. Syst. Saf.*, vol. 252, p. 110447, Dec. 2024, doi: 10.1016/j.ress.2024.110447.

[58] G. T. S. Ho, Y. M. Tang, K. Y. Tsang, V. Tang, and K. Y. Chau, "A blockchain-based system to enhance aircraft parts traceability and trackability for inventory management," *Expert Syst. Appl.*, vol. 179, p. 115101, Oct. 2021, doi: 10.1016/j.eswa.2021.115101.

[59] Nafiurridha and A. Choiruddin, "Classifying MRP Strategy of Aircraft Spare Parts Using Supervised Machine Learning," *Procedia Comput. Sci.*, vol. 234, pp. 470–477, 2024, doi: 10.1016/j.procs.2024.03.029.