Demand Control Loops for a Global Spare Parts Management

Uwe Dombrowski, Sebastian Weckenborg, Michael Mederer

Demand control loops for a global spare parts management

Uwe Dombrowski[1], Sebastian Weckenborg[1], Michael Mederer[2]

[1]Technische Universität Braunschweig,
Institute for Advanced Industrial Management,
Langer Kamp 19, 38106 Braunschweig, Germany

[2]m[2]hycon, 55270 Ober-Olm, Germany

Abstract. Timely, reliable supply of customers with spare parts is a key factor for business success in many branches. In the field of aviation the competition and cost pressures in the MRO sector (Maintenance, Repair and Overhaul) increased strongly in recent decades. Large maintenance organizations offer component pooling services for aircraft operators. A main challenge in the processes of MRO service providers is the calculation of the optimal stock level for pool components. The basis of an optimal inventory planning for the supply of spare parts is the quality of the demand input parameters used for the calculation. This paper describes the processes and the challenges of the MRO spare parts management as well as the approaches of a research project to face these challenges.

Keywords: Spare Parts Management, MRO, Maintenance, Repair, Overhaul

1 Introduction

The efficient delivery of spare parts during the entire life cycle of the product is a differentiating quality characteristic in competition that leads to improved customer loyalty and, therefore, strengthens the company in the market. Changing conditions, such as the increasing number of product variants with rapidly shortened innovation cycles and increased competition in many sectors, are new challenges in the spare parts business, which the companies have to meet. In the field of electronics the situation is more complicated. Electronic components are generally built for the entire life cycle of the primary product (e.g. cars or aircrafts). Nevertheless, a failure may occur during the life cycle of the component. This can be the result of internal influences, e.g. production failures, or external influences like an accident. [1]

In the field of aviation the competition and cost pressures in the MRO sector (Maintenance, Repair and Overhaul) increased strongly in recent decades. The main goal of a MRO service provider is to ensure on-time supply of spare parts. In addition, the spare parts inventory and thus the capital costs and process costs have to be minimized. Spare parts logistics and inventory planning therefore are a major challenge in globally networked structures.

APMS Conference, p. 1, 2012.

Four main characteristics of the spare parts supply in the field of aviation are the global need for parts, the demand unpredictability, the traceability of parts for safety reasons and especially the high cost of not having a part. The latter situation is called AOG (Aircraft on Ground). [2] In order to avoid long-term ground time of an aircraft and an AOG situation, so-called Line Replaceable Units (LRU) are used in aircrafts when possible. A change of these LRUs is carried out quickly and the aircraft is therefore immediately ready for use again. Meanwhile, the exchanged part is repaired or overhauled and preserved for the next installation.

2 Inventory Pooling

2.1 Description of the processes of inventory pooling

In addition to the standard maintenance services, large maintenance organizations sometimes offer a component pooling service for aircraft operators. According to the individual user agreements the pool participants get access to the pooled aircraft components. If a defect of a component occurs and a pool contract is closed through the customer and the MRO service provider, a new component is provided by the pool provider. The pool provider can also be the MRO service provider at the same time. In this case the component will be replaced by a new or repaired pool component directly by the MRO service provider. Meanwhile, the removed part will be analyzed in a service center of the pool provider and depending on technical and economic aspects the decision is made whether the component will be repaired or replaced. [3], [4]

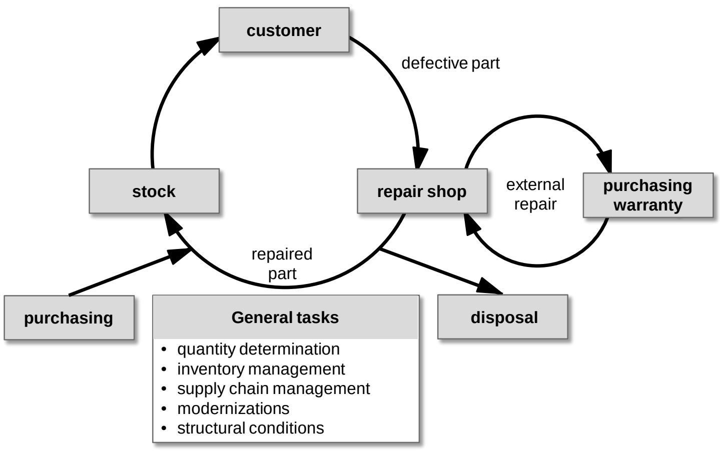


Fig. 1. Tasks of the MRO service provider [3]

The task of the MRO service provider is to ensure the availability of the spare parts. The general process of the inventory pooling service is shown in Fig. 1. The process starts with the delivery of the defective part by the customer. The MRO service provider analyzes the part in the repair shop and decides whether it can be repaired in the own repair shop or it could be done by an external repair shop. The disposal of parts and the purchase of new parts are options as well. In the meantime the customer is supported with another part from the stock of the service provider. General tasks of the service provider are the determination of the repair float quantity of parts and the inventory management, the supply chain management, the management of modernizations and the tracking of structural condition of spare parts. [3], [4]

The participation in inventory pooling may lead to the following advantages. The first advantage is the utilization of experiences and synergies as well as economies of scale of large MRO service providers and thus reducing operating costs. In particular this applies to airlines with smaller fleets. Another advantage is an increased availability of components away from the home base and thereby higher aircraft operational capability. Finally inventory pooling may lead to predictable maintenance costs and usage-based pool contributions (e.g. based on flight hours or flight cycles). [4]

2.2 Challenges within the framework of inventory pooling

A main challenge in the processes of MRO service providers is the calculation of the optimal stock level of the pool components. The stock level has an influence on the service level and therefore on the customer satisfaction and on the other hand on the profitability of the processes. The basis of an optimal inventory planning for the supply of spare parts is the quality of the input parameters used for the calculation. The optimal stock level is highly influenced by the demand of the customers. The demand is furthermore influenced by different impact factors, which can be divided in four categories. Impact factors related to the primary product, impact factors related to the spare part, impact factors related to the maintenance and impact factors related to the market situation and other surroundings (Fig. 2) [5].

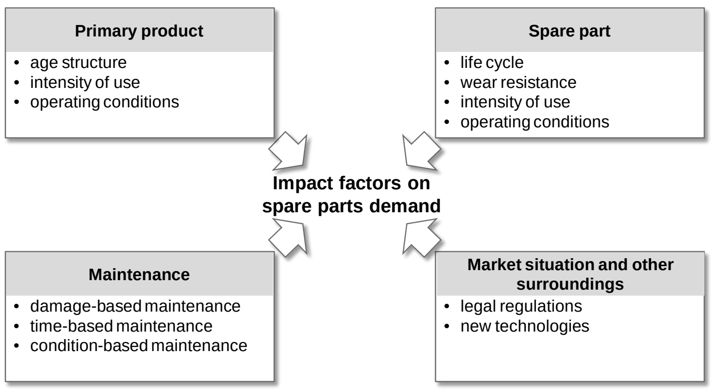


Fig. 2. Impact factors on spare parts demand [5]

Primary product-related factors include the age structure of the primary products, the intensity of use and the operating conditions. In addition to the life cycle of the primary products, the life cycle of the spare parts is important. An increased life cycle of the spare parts leads to a lower demand. In this case as well, factors such as wear resistance, usage and operating conditions play through its own activities an important role. The MRO service provider has also an impact on the spare parts requirements. The MRO service provider can use different maintenance strategies which also could have an influence on the demand of spare parts: the damage-based, the time-based and the condition-based maintenance strategy. In the first case parts are replaced after a defect. In the second case parts are replaced according to specified time intervals, independently of their condition. In the third case parts are checked as part of inspections and are replaced if necessary. Finally the spare parts demand is also influenced by the market situation, e.g. legal regulations or the introduction of new technologies. [5]

3 Demand control loops for a global MRO spare parts management

The main objective of this research project is the development of demand control loops for a global MRO spare parts management. For this purpose different sub objectives have to be achieved. The first sub objective is the calculation of the mean durability of different parts and the second sub objective is the analysis of the requirements for an organizational implementation. In the following part of this paper the sub objectives are described.

3.1 Calculation of the Mean Durability of different parts

The failure of LRU parts leading to unscheduled removals can be modeled as stochastic renewal process, where often the demand is rather sparse. Historically the distribution of this demand has been modeled as a Poisson process, where the inter-arrival times (e.g. flight times) between two removals are exponentially distributed. Additional complexity arises when incorporating removals resulting from hard-time requirements, condition-based maintenance and/or maturity characteristics of the material (non-homogenous stochastic process).

A basic approach described in literature to approximate the demand (D) in the aviation industry is in form of a correlation to the intensity of use. It is assumed that the demand (failure rate) is proportional either to the flight hours (FH), the flight cycles (FC) or the calendar time (CT) per part number depending on the type of material in question. [6]

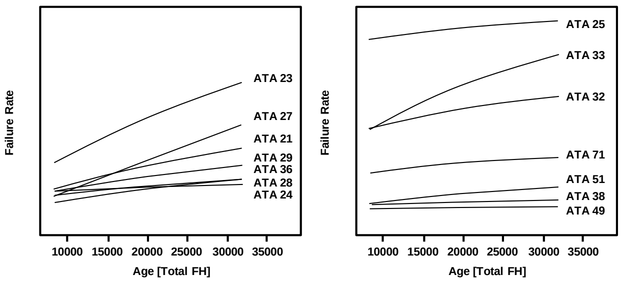
$$D = \frac{FH}{MTBR} \quad or \quad D = \frac{FC}{MCBR} \quad or \quad D = \frac{CT}{MDBR} \tag{1}$$

The denominator represents the mean durability in terms of type of usage. The Mean Time Between Removal (MTBR), the Mean Cycles Between Removal (MCBU) and the Mean Duration Between Removal (MDBR) can be differentiated.

Due to the sparsity of the data, there are two major challenges in this approach that will be analyzed in this research work. Firstly, the mean durability is often calculated from historic data. However, the finite observation window cuts off a significant amount of data and therefore interferes with the data. Given this fact Zhao [7] has shown, that the stochastic distribution of demand strongly influences the method of calculating the mean in (1). He shows that the calculations (1) are of good quality only for the Poisson distribution assumption.

Secondly, the influences of additional factors will be examined as part of the research work in this project. A distinction between measurable impact factors and categorical impact factors is useful. Measureable impact factors are e.g. the number of flight hours, the number of flight cycles and the calendar time between the appearances of maintenance events. Categorical impact factors are e.g. the aircraft type, the operator, regional influences of climatic conditions, seasonal influences or the usage profile of the customer (e.g. long-distance or short-distance) [8]. The identified impact factors have to be checked by relevance and suitability. Furthermore the dependencies between the impact factors have to be analyzed.

The influence of the age of the primary product is exemplarily shown in Fig. 3. In an analysis of different ATA chapters (Air Transport Association), a standard numbering system, a dependency of the failure rate and the age in flying hours has been determined. [9] An analysis on the basis of the ATA chapter is probably no appropriate reference level as different material numbers are assigned to the ATA chapters. The appropriate reference level has therefore to be analyzed.



ATA Chapter	System
21	Air Conditioning
23	Communications
24	Electrical Power
25	Equipment & Furnishing
27	Flight Controls
28	Fuel
29	Hydraulic Power
32	Landing Gear
33	Lights
36	Pneumatic
38	Water & Waste
49	Auxilliary Power Unit
„51" – 51,53,54,55,57	„Structures"
„71" – 71 to 80	„Engines"

Fig. 3. Influence of the age of an aircraft on the failure rate of components [9]

For a forecast of the future demands the historical plan demands have to be constantly matched with the actual demand. By the permanent matching of the plan demand with the actual demand the control loops can be established. In the first step the identified relevant impact factors are set by the initially calculated value and should constantly be optimized. Approaches for forecasting methods in this context can exemplary be found in [10], [11], [12], [13], [14].

Of special importance is the measurement of the forecast quality. Table 1 shows an excerpt from the existing data base used in this project (data anonymized, values changed). Each line represents a change of a component. The table contains the changes of components and their material properties and their exchange properties.The material properties are the material code, the material group and the material number. The material code describes a technical function in an aircraft. In a material group several material numbers are combined, which are completely interchangeable. The level of detail increases from the material code up to the material number. The previously described ATA chapter is in the detail level several steps above the material code. These three groups are chosen to illustrate the approach. Even more detailed material properties, for example the serial number, are available in practice. In addition to the material properties the exchange properties are shown in table 1. These are on one hand measureable impact factors such as the flight hours, the flight cycles and the calendar time and on the other hand the categorical impact factors such as the operator and the aircraft type, which are listed as examples. For each component change this information is recorded.

Table 1. Example of the structure of the data base

number	material code	material group	material number	operator	aircraft type	...	flight hours	flight cycles	calendar time
1	material code 1	material group 1	material number 1	operator 1	A330	...	13245	2835	39120
2	material code 1	material group 1	material number 1	operator 2	A330	...	9682	4494	29760
3	material code 1	material group 1	material number 1	operator 2	A340	...	9007	3452	19608
4	material code 1	material group 1	material number 2	operator 3	747	...	14864	1183	16533
5	material code 1	material group 2	material number 3	operator 1	777	...	1617	1306	5808
6	material code 1	material group 2	material number 3	operator 2	A320	...	7420	6387	26808
7	material code 1	material group 2	material number 4	operator 1	747	...	8979	7362	32880
8	material code 1	material group 2	material number 4	operator 3	A320	...	4950	4020	27600
9	material code 1	material group 2	material number 4	operator 2	A330	...	10870	9000	38400
10	material code 1	material group 2	material number 4	operator 2	A330	...	9703	6973	29488
11	material code 1	material group 3	material number 5	operator 1	747	...	8979	7362	32880
12	material code 1	material group 3	material number 5	operator 3	A320	...	4950	4020	82800
13	material code 1	material group 3	material number 5	operator 3	747	...	8501	7103	29976
14	material code 1	material group 3	material number 6	operator 2	747	...	5194	4471	18766
...	...	...	...	...	...	...	...	...	...

Based on the existing component changes reference values are generated for the demand forecast. For this, the complete data set is separated into two random data sets, a training set and a test set. By these separate data sets demand forecasts can be generated by the training set and finally the quality of the forecast can be reviewed on the basis of the test set. In table 2 the division of the data is shown.

Table 2. Calculation of the mean durability in terms of type of usage as a reference value

number	material code	material group	flight hours	flight cycles	calendar time	set by chance	MTBR (calculated)	MCBR (calculated)	MDBR (calculated)
1	material code 1	material group 1	13245	2835	39120	training	11464	3665	34440
2	material code 1	material group 1	9682	4494	29760	training			
5	material code 1	material group 2	1617	1306	5808	training	7155	5889	25696
7	material code 1	material group 2	8979	7362	32880	training			
9	material code 1	material group 2	10870	9000	38400	training			
12	material code 1	material group 3	4950	4020	82800	training	6726	5562	56388
13	material code 1	material group 3	8501	7103	29976	training			

number	material code	material group	flight hours	flight cycles	calendar time	set by chance	D_{MTBR}	D_{MCBR}	D_{MDBR}
3	material code 1	material group 1	9007	3452	19608	test	0,8	0,9	0,6
4	material code 1	material group 1	14864	1183	16533	test	1,3	0,3	0,5
6	material code 1	material group 2	7420	6387	26808	test	1,0	1,1	1,0
8	material code 1	material group 2	4950	4020	27600	test	0,7	0,7	1,1
10	material code 1	material group 2	9703	6973	29488	test	1,4	1,2	1,1
11	material code 1	material group 3	8979	7362	32880	test	1,3	1,3	0,6
14	material code 1	material group 3	5194	4471	18766	test	0,8	0,8	0,3
						∑	7,3	6,3	5,2

In this example the material group is chosen as a reference. Based on the material group the MTBR, MCBR and MDBR are calculated in the training set. With the values determined in the training set, the resulting changes in the test set according to formula (1) are calculated. These values are compared to actual changes, which in this specific test set turn out to be 7. In comparison 7.3 changes are determined with the calculated MTBR based on the training set. Furthermore 6.3 changes are determined with the calculated MCBR and 5.2 changes are identified with the calculated MDBR. Thus, the best forecast value is calculated by the use of the MTBR. In other words, the flight hours have the most significant impact on the number of changes. These values have to be validated by repeated random separation of the data into a training and a test set. By combining different material and exchange properties other influencing factors can be analyzed. The combination of (material group x operator), (material group x aircraft type) or (material group x operator x aircraft type) are only a few possible combinations in this example.

3.2 Analysis of the requirements for an organizational implementation

The analysis of the requirements for an organizational implementation is another topic in the research project. Different departments of an organization have varying requirements regarding the use of the calculated demands. E.g. a repair shop needs the demand to schedule the work orders or the technology management uses the information in the context of the reliability analysis. To determine the Repair Float Quantity (RFQ) this information is used in the materials planning. It should be examined whether it is possible to develop an universal approach which generates the corresponding varying values for the different departments on the basis of a consistent data selection.

4 Summary

The efficient delivery of spare parts during the entire life cycle of the product is a differentiating quality characteristic in competition that leads to improved customer loyalty and, therefore, strengthens the company in the market. In the field of aviation the competition and cost pressures in the MRO sector increased strongly in recent decades. The main goal of a MRO service provider is to ensure on-time supply of spare parts and a main challenge in the processes of MRO service providers is the calculation of the optimal stock level of the pool components which is influenced by different impact factors. The main objective of this research project is the development of demand control loops for a global MRO spare parts management. Due to the sparsity of the data, there are two major challenges in this approach that will be analyzed in this research work. Firstly, the calculation of the mean durability of components and the integration of the influences of additional factors like regional influences of climatic conditions. Finally the requirements for an organizational implementation are another topic in this research project.

5 Acknowledgements

The results presented in this paper were developed in the research project "Demand control loops for a global component spare parts management". This research project is part of the regional aviation research program LUFO II-2 funded by the German Federal State of Hamburg (Behörde für Wirtschaft, Verkehr und Innovation).

6 References

1. Dombrowski, U., Schulze, S., Vollrath, H.: Klassifizierung kritischer Elektronikbauelemente unter Lebenszyklusaspekten. automotive 11, 34-37 (2009)
2. Ghobbar, A.A., Friend; C.H.: Sources of intermittent demand for aircraft spare parts within airline operations. Journal of Air Transportation Management 8, 221-231 (2002)
3. Schmidt, T., Laucht, O., Bauer, A.: Mehrwert schaffen durch Fokussierung auf das Servicegeschäft. In: Barkawi, K., Baader, A., Montanus, S. (eds.): Erfolgreich mit After Sales Service: Geschäftsstrategien für Servicemanagement und Ersatzteillogistik. pp. 95-111. Springer, Heidelberg (2006)
4. Hinsch, M.: Industrielles Luftfahrtmanagement: Technik und Organisation luftfahrttechnischer Betriebe. Springer, Berlin (2010)
5. Loukmidis, G., Luczak, H.: Lebenszyklusorientierte Planungsstrategien für den Ersatzteilbedarf. In: Barkawi, K., Baader, A., Montanus, S. (eds.): Erfolgreich mit After Sales Service: Geschäftsstrategien für Servicemanagement und Ersatzteillogistik. pp. 250-270. Springer, Heidelberg (2006)
6. Linser, A.: Performance Measurement in der Flugzeuginstandhaltung. Dissertation. Universität, Hochschule für Wirtschafts-, Rechts- und Sozialwissenschaften (HSG), St. Gallen (2005)
7. Zhao, Y.: Parametric interference from window censored renewal process data. Dissertation. Ohio State University (2006)
8. Bauer, A.: Lebenszyklusorientierte Optimierung von Instandhaltungssystemen für hochwertige Investitionsgüter. Dissertation. Shaker, Aachen (2002)
9. Wagner, M., Fricke, M.: Estimation of daily unscheduled line maintenance events in civil aviation. In: 25th International Congress of Aeronautical Science, Hamburg (2006)
10. Luxhøj, J. T., Trefor P. W., Shyur, H.-J.: Comparison of regression and neural network models for prediction of inspection profiles for aging aircraft. IIE Transactions 29, 91-101 (1997)
11. Ghobbar, A.A., Friend; C.H.: Evaluation of forecasting methods for intermittent parts demand in the field of aviation: a predictive model. Computers & Operations Research 30 2097–2114 (2003)
12. Regattieri, A., Gamberi, M., Gamberini, R., Manzini, R.: Managing lumpy demand for aircraft spare parts. Journal of Air Transport Management 11, 426–431(2005)
13. Bevilacqua, M., Braglia, M., Frosolini, M., Montanari, R.: Failure rate prediction with artificial neural networks. Journal of Quality in Maintenance Engineering 3, 279–294 (2005)
14. Louit, D.M., Pascual, R., Jardine, A.K.S.: A practical procedure for the selection of time-to-failure models based on the assessment of trends in maintenance data. Reliability Engineering and System Safety 94, 1618–1628 (2009)