Determination of the Spare Parts Demand for Maintenance, Repair and Overhaul Service Providers

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Abstract. Service providers for maintenance, repair and overhaul (MRO) of aircrafts and components face major challenges. The calculation of an optimal stock level for components is one of these. The optimal stock level is highly influenced by the customers demand. Furthermore the stock level influences the profitability of the processes. The challenge for MRO service provider is to respond to the changing customer base and to adapt the stock level for components dynamically. For this purpose, an approach for the determination of the spare parts demand is described in this paper. The approach consists of a hierarchical derivation of reliability parameters in the first step and finally an assessment of the derived reliability parameters. By this assessment the relevance of different impact factors can be determined. The determination of the spare parts demand and the optimal stock level can thereby be determined much more accurately.

Keywords: Spare parts management, MRO, Maintenance, Repair, Overhaul

1 Introduction

The efficient spare parts supply during the entire life cycle of the primary product is a differentiating quality characteristic in competition. It can lead to an improved customer satisfaction and strengthens the company in the market. [1], [2], [3]

For the realization of an effective spare parts management, it is important to understand the correlations between different impact factors regarding the spare parts demand. Both the life cycle of the primary product and the life cycle of the component have to be considered. There are different strategies for the spare parts supply during and after the serial production of the primary product. These result from the number of primary products on the market and especially from the technological characteristics of the individual components as well as the reliability parameters. This results in different demand patterns, not only in volume, but also in demand continuity and the demand predictability. [4], [5], [6], [7]

The life-cycle-oriented spare parts management focuses on this specific problem and contains several supply strategies to realize an efficient post-series supply. These supply strategies are the development of a compatible successive product generation, the storing of a final lot, the periodical internal or external production, the reuse of used components and the repair of used components. [8], [9], [10]

The aviation industry is characterized by extremely long life-cycles of the primary products with a high degree of efficiency, small lot sizes, a strict regulation and a high degree of individualization. The share of the services business in the aviation industry is very high. [11] Airlines often buy the maintenance services, in order to concentrate on their core business. Compared with other industries, the repair of components in the aviation industry is highly profitable and is therefore common practice [12]. [13]

2 Tasks and Challenges of Maintenance, Repair and Overhaul Service Providers

The range of tasks of a service provider in the aviation field is very large. A classification of the tasks is possible by the distinction between the value adding organizational units of a service provider. These organizational units are the spare parts supply, the spare parts maintenance, the logistics and the aircraft maintenance. The supply of spare parts and spare parts maintenance form the spare parts management which is in the focus of this paper. [14], [15]

The spare parts supply has the inventory and planning responsibility for the spare parts. The spare parts maintenance can be seen as a service for the spare parts supply. The spare parts maintenance is responsible for the repair of spare parts. For this purpose, the spare parts maintenance has its own manufacturing and workshop areas. By the logistics the spare parts are transported from/to the customer. The aircraft maintenance takes place on the basis of strict regulations within different maintenance events. [14]

To avoid long-term ground time of an aircraft, 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. [16] Furthermore large service providers sometimes offer a component pooling service for aircraft operators. If a defect of a component occurs a new component is provided by the pool provider. The removed part will be analyzed by the service provider afterwards and depending on technical and economic aspects the decision is made whether the component will be repaired or replaced. [11], [15]

In the context of the spare parts supply the determination of the spare parts demand is a major challenge, especially for service providers. [14], [17] This is caused by a variety of different aspects. The primary products in the aviation industry have very long life cycles. On average, aircrafts fly over 20 years. This leads to many different generations of aircraft and many different generations of components which should be supplied by a service provider. Electronic components in today's aircrafts are from the period in which the aircraft were developed. Furthermore the costs of the components in the aviation industry are very high. Because of these high costs, the very long life-cycles, the small amounts of components the repair of components in the aviation industry is highly economical. [11] The failure behavior of many components is not known, the absolute number of failures of a specific component is usually very low. It can be assumed that the different generations of components installed have different failure rates. In many cases, the information about the components installed is missing. This is because the cost of the identification would be very high and also the operator of an aircraft does not have this information. This may be because the operator has leased the aircraft. In this case the probabilities of installation for different components have to be determined.

3 Approach for Determination of Spare Parts Demands

3.1 Impact factors regarding the spare parts demand

A basic approach for the determination of the spare parts demand (D) is by using the correlation of the intensity of use for a future period and the failure rate of a component [18]. This and other approaches, however, are only partially applicable for MRO service providers. Other approaches can exemplary be found in [19], [20], [21], [22], [23]. While the intensity of use of the primary product (the aircraft) can be determined well, there are difficulties in determining the intensity of use of a component of the aircraft. This is due to the fact that the components used are often not known. This complicates the determination of a reliable failure rate for different components. However, the knowledge about the impact factors regarding the failure rate and thus the spare parts demand is essential for a MRO service provider.

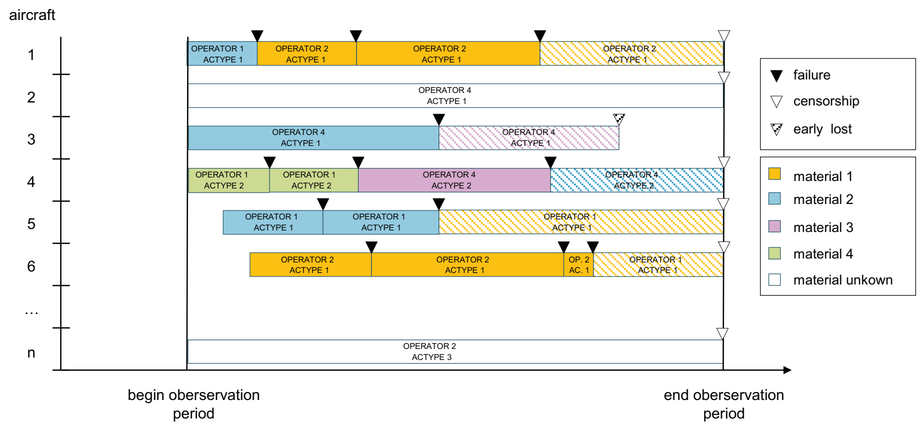

Fig. 1. Data base in a certain observation period

In figure 1 the existing data base and the uncertainties are shown exemplarily. The failures of materials are recorded in a certain observation period for different aircrafts. By the definition of the observation period the data is censored at the beginning and at the end of this period. Furthermore, the data of aircrafts, in which the components are not known, is recorded to. All censored data is considered in the analysis.

Different impact factors regarding spare parts demand are mentioned in literature. These impact factors can be assigned to the primary product, the spare part itself, the maintenance strategy or to the market situation and other surroundings [13], [17]. For simplicity, in the following part the focus will be on a limited number of impact factors. The approach allows the integration of further and other impact factors.

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). In the following these impact factors are described as measurable impact factors. Furthermore categorical impact factors are assumed. These can be the aircraft type, the operator of the aircraft and the material which is used, for example. The influence of these factors has been shown in different studies [16] but in general the relationship between the mean demand and flying hours or flight cycles is not well understood [24].

3.2 Hierarchical derivation of reliability parameters

The assessment of impact factors regarding the spare parts demand of MRO service providers is a main objective of this approach. In the context of the assessment of the impact factors the handling of the uncertainties is an important aspect, which is not in the focus of this paper. It is important to know that the uncertainties about the components used are closely linked to the assessment of the impact factors.

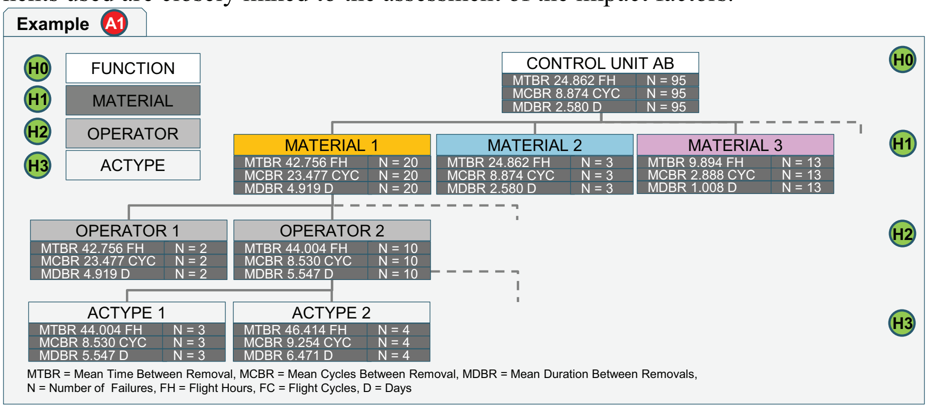

Fig. 2. Hierarchical derivation of reliability parameters

The assessment of the impact factors is done for a technical function in an aircraft. This could be a flight management computer, for example. In a first step the categorical impact factors are combined according to their potential relevance in any combination. For three different impact factors six different combinations can be created. Each combination represents a hierarchical alternative for the impact factors.

In figure 2 a hierarchical alternative is shown as an example. The first level is always represented by the technical function (H0). In this example the second level is defined by the material (H1), underlying the operator (H2) and finally the aircraft type (A3). A technical function is always defined by all impact factors. This means it is defined by a certain material, an operator and an aircraft type. However, it is not useful to determine an individual reliability parameter for each possible combination. One reason for this is the large variance of possible failure intervals. Because of this the significance of each combination is analyzed. With the three measurable impact factors (FH, FC, CT) three different reliability parameters can be derived. The mean time between removal (MTBR), the mean cycles between removal (MCBR) and the mean duration between removal (MDBR). These are calculated by the sum of all flight hours (or all flight cycles or the calendar time) of the whole aircraft population (m), multiplied with the quantity per aircraft of the component (QPA) in a certain observation period divided by the number of failures (see equation 1). [12]

$$MTBR = \frac{\sum_{i=1}^{m} QPA_i * FH_i}{n}\,[FH],\ MCBR = \frac{\sum_{i=1}^{m} QPA_i * FC_i}{n}\,[FC],\ MDBR = \frac{\sum_{i=1}^{m} QPA_i * CT_i}{n}\,[\mathrm{D}] \qquad (1)$$

At each step from one to the next hierarchical level, it is checked whether a separation of the failure rate regarding the overlying hierarchical level is significant. If the reliability parameter is significantly different this value is separated and the underlying hierarchical level receives an individual reliability parameter. In figure 2 material 1 and material 3 are determined to be significant. Material 2 is not significantly different from the technical function and the reliability parameter is set the same as the reliability parameter of technical function. The significance is analyzed in each hierarchical level.

3.3 Assessment of the derived reliability parameters

The derived reliability parameters are assessed in the next step. For this purpose the complete data set has been separated into two random data sets. The determination of the reliability parameters is done on the trainings set and the quality of these is reviewed on the basis of the test set. With the values determined in the training set, the resulting changes in the test set are calculated. [17]

Table 1. Assessment of the derived reliability parameters

					reliability parameter			actual changes				calculated changes			measure		
					[FH]	[CYC]	[D]		[FH]	[CYC]	[D]						
	FUNCTION	MATERIAL	OPERATOR	ACTYPE	MTBR	MCBR	MDBR	N	FH	CYC	D	MTBR	MCBR	MDBR	MTBR	MCBR	MDBR
A1	CONTROL UNIT AB	MATERIAL 1	OPERATOR 1	ACTYPE 1	41.245	7.536	4.765	4	214.474	38.282	17.344	5,20	5,08	3,64	1,44	1,17	0,13
A1	CONTROL UNIT AB	MATERIAL 1	OPERATOR 1	ACTYPE 2	40.293	7.430	8.374	3	139.010	26.079	25.373	3,45	3,51	3,03	0,20	0,26	0,00
A1	CONTROL UNIT AB	MATERIAL 1	OPERATOR 2	ACTYPE 1	44.004	8.530	5.547	4	197.137	40.261	10.428	4,48	4,72	1,88	0,23	0,52	4,49
A1	CONTROL UNIT AB	MATERIAL 1	OPERATOR 2	ACTYPE 2	44.004	8.530	5.547	2	93.288	13.989	9.873	2,12	1,64	1,78	0,01	0,13	0,05
A1	CONTROL UNIT AB	MATERIAL 2	OPERATOR 1	ACTYPE 1	24.862	8.874	2.580	1	23.370	9.850	2.167	0,94	1,11	0,84	0,00	0,01	0,03
A1	CONTROL UNIT AB	MATERIAL 2	OPERATOR 2	ACTYPE 1	19.872	5.472	2.092	2	47.295	10.725	4.727	2,38	1,96	2,26	0,14	0,00	0,07
A1	CONTROL UNIT AB	MATERIAL 3	OPERATOR 1	ACTYPE 1	7.832	2.834	1.402	3	22.321	6.886	6.981	2,85	2,43	4,98	0,02	0,33	3,92
A1	CONTROL UNIT AB	MATERIAL 3	OPERATOR 1	ACTYPE 2	9.894	2.888	1.008	4	33.243	13.862	6.289	3,36	4,80	6,24	0,41	0,64	5,01
A1	CONTROL UNIT AB	MATERIAL 3	OPERATOR 2	ACTYPE 1	7.832	2.834	1.402	5	41.118	15.587	3.505	5,25	5,50	2,50	0,06	0,25	6,25
												Root-mean-square error			0,5302	0,6058	1,4888
A5	CONTROL UNIT AB	MATERIAL 1	OPERATOR 1	ACTYPE 1	38.273	7.432	2.876	4	214.474	38.282	17.344	5,60	5,15	6,03	2,57	1,32	4,12
A5	CONTROL UNIT AB	MATERIAL 1	OPERATOR 1	ACTYPE 2	32.754	4.732	4.873	3	139.010	26.079	25.373	4,24	5,51	5,21	1,55	6,31	4,87
A5	CONTROL UNIT AB	MATERIAL 1	OPERATOR 2	ACTYPE 1	38.273	7.432	2.876	4	197.137	40.261	10.428	5,15	5,42	3,63	1,32	2,01	0,14
A5	CONTROL UNIT AB	MATERIAL 1	OPERATOR 2	ACTYPE 2	39.283	7.463	2.743	2	93.288	13.989	9.873	2,37	1,87	3,60	0,14	0,02	2,56
A5	CONTROL UNIT AB	MATERIAL 2	OPERATOR 1	ACTYPE 1	22.735	4.736	1.734	1	23.370	9.850	2.167	1,03	2,08	1,25	0,00	1,17	0,06
A5	CONTROL UNIT AB	MATERIAL 2	OPERATOR 2	ACTYPE 1	38.273	7.432	2.876	2	47.295	10.725	4.727	1,24	1,44	1,64	0,58	0,31	0,13
A5	CONTROL UNIT AB	MATERIAL 3	OPERATOR 1	ACTYPE 1	4.872	1.648	1.220	3	22.321	6.886	6.981	4,58	4,18	5,72	2,50	1,39	7,41
A5	CONTROL UNIT AB	MATERIAL 3	OPERATOR 1	ACTYPE 2	14.230	1.972	1.543	4	33.243	13.862	6.289	2,34	7,03	4,08	2,77	9,18	0,01
A5	CONTROL UNIT AB	MATERIAL 3	OPERATOR 2	ACTYPE 1	5.364	2.463	1.102	5	41.118	15.587	3.505	7,67	6,33	3,18	7,11	1,76	3,31
												Root-mean-square error			1,4354	1,6146	1,5849
basis: training set								basis: test set									

The deviation between the actual changes and the calculated changes is used as a measure for the quality of forecast. This is done for each hierarchical alternative and each reliability parameter. By repeating this random separation of the data set into two data sets the best hierarchical alternative as well as a best reliability parameter (MTBR, MCBR and MDBR) can be determined. An example of this assessment is shown in table 1. This example shows two different hierarchical alternatives (A1 and A5) and the reliability parameter for the different combinations. In this example the MTBR is the best reliability parameter and the relevance of the impact factors is set by the hierarchical alternative A1. In the next step it should be analyzed whether it is possible to determine the relative influence of the different reliability parameters.

3.4 Customer projects of MRO Service Providers

The integration of new customers, new components or new aircraft types, for example, is a recurring and challenging task for MRO service providers. These integrations are called customer projects in general and are a special characteristic of MRO service providers. [14] Due to missing information regarding material, aircraft type or customer it is difficult to assign a reliability parameter.

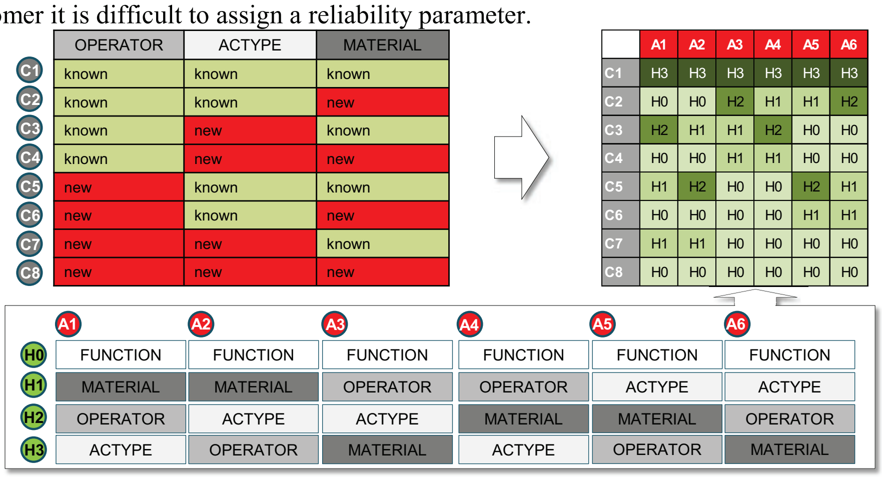

Fig. 3. Application of hierarchical derivation on customer projects

Different forms of customer projects can be distinguished. In figure 3 different customer projects are shown. Out of three different impact factors eight customer projects can be derived. The customer projects can be differentiated whether an impact factor is known or new. The complexity increases significantly by adding additional impact factors. In customer project C3, for example, a known customer wants to be supplied with a known material, which is installed in a new aircraft type. For this technical function the hierarchical alternative A4 has been determined methodically. In combination, in this customer project the reliability parameter of the hierarchical level H2 should be used. By the hierarchical assessment of the impact factors it is possible to react to missing information accordingly.

4 Summary

The efficient spare parts supply during the entire life cycle of the primary product is a differentiating quality characteristic in competition. For the realization of an effective spare parts management, it is important to understand the correlations between different impact factors regarding the spare parts demand. The aviation industry is characterized by extremely long life-cycles of the primary products with a high degree of efficiency, small lot sizes, a strict regulation and a high degree of individualization. In the context of the spare parts supply the determination of the spare parts demand is a major challenge, especially for service providers. Existing approaches for the determination of the spare parts demand are only partially applicable for MRO service providers. These challenges are faced in a new approach. Within this approach the relevance of different impact factors can be determined and the stock can thereby be analyzed much more accurately. Therefore the cost effectiveness of the services and the customer satisfaction can be increased.

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