Operations management systems of aircraft maintenance companies

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Abstract
This study aims to assess the operations management systems of aircraft maintenance companies. To this objective, we conducted a survey of group of aircraft maintenance companies in Brazil. We identified seven factors among which two factors, handling maintenance manuals and communication in maintenance operations, were more relevant.

Keywords: Operations Management Systems, Aircraft Maintenance, Factorial Analysis.

Introduction
Brazilian domestic market of air transport is the largest of Latin America (Araújo et al., 2007), and it has grown at a rate of 10% between 2003 and 2008, reaching more than 50 million trips per year (McKinsey & Company, 2010) . According to the study elaborated by McKinsey, it is likely that this sector will continue to grow at very relevant rates due to the expected income growth, which are expected to impact the demand for air transport, mainly of the lower income classes and poorest regions of Brazil. Comparative data for the period August 2009 to August 2010, published by the ANAC (National Agency of Civil Aviation) show a compound annual growth rate in demand of nearly 34% for domestic flights market and 28.5% for the foreign market.
Such growth in air transport industry requires aircraft maintenance services capable of supporting such an expansive process, without neglecting the conditions of flight safety. Insofar as the expected air transport growth is associated to a country like Brazil, which is characterized by having a large territory with a strong civil and military air traffic, linking the various regions of the country, then aircraft maintenance service companies have to develop managerial capabilities, in order to support air transport expansion. Therefore, in the context of such managerial dimension, it emerges the following research question that leads this paper: "What are the managerial factors taken into account in current management practices of Brazilian aviation maintenance companies?"

Some of the works found in the literature review explores the aircraft maintenance perspectives that seek to improve the efficiency of the sector. As an example, Birth (2006) and Rodrigues et al. (2010) study the perspective of costs, while Ando & Costa (2004) and Papakostas et al. (2010) concentrate their efforts in the selection of maintenance strategies. Moreover, Vilela, et al. (2010) analyzed the relationship of maintenance to aircraft accidents and recommendations for operational safety. Some of the works found in the literature review

explores the aircraft maintenance issues on perspectives that seek to improve the efficiency of the sector. As an example, Birth (2006) and Rodrigues et al. (2010) study the perspective of costs, while Ando & Costa (2004) and Papakostas et al. (2010) concentrate their efforts in the selection of maintenance strategies. Moreover, Vilela, et al. (2010) analyzed the relationship of maintenance to aircraft accidents and recommendations for operational safety. Other authors also focus on classical issues of the aircraft maintenance literature, such as the analysis of maintenance systems for fault diagnosis (Silva Filho et al., 2005); the reliability and its relationship with cost control (KILLS SON et al., 1998); the maintenance planning (Samaranayake, 2006; Samaranayake et al, 2007). Nevertheless, the review of the relevant academic literature have revealed that this subject has received little attention from the academic community, opening opportunities for research. Indeed, it is noted that several studies focus on issues related to the managerial and technical-economic dimensions, at the level of the company or industry. Thus, Moroni (2003) studied management models based on a system of indicators, with application to aircraft maintenance service companies, while Machado et al. (2009) make a preliminary analysis on the managerial capability of Brazilian maintenance companies of aeronautical material, using as reference a the European model of the maintenance process (EURESPACE, 2003). Also, Durand (2008) examines the relevant aspects of the management of aircraft maintenance, related to expected changes in the organizational structure of the U.S. Air Force maintenance, as a result of the implementation of a resource planning system. With a slightly wider scope, and tangentially addressing the aircraft maintenance, the work of Paulino & Oliveira (2007) discusse the potential for innovation of recent cluster of aeronautical production and maintenance established in the central region of the state of São Paulo, in Brazil. Therefore, this study aims to assess the management systems of aircraft maintenance companies in Brazil with regard to their management practices, and identify which managerial factors are more relevant for those companies. For this, it was utilized data from a survey of an expressive group of businesses that are part of the sector. The results revealed that Brazilian maintenance companies consider the control and handling of maintenance manuals, and the maintenance operations in communication, as the most important of the seven factors identified.

Aircraft maintenance in Brazil

The aircraft maintenance can be divided into two activities, although they are completely attached, they have specific characteristics that distinguish them. The first activity refers to the maintenance of aircraft equipment as a single, and the second refers to the maintenance activity of the components that serve as inputs to the first. This distinction is necessary because the characteristics of aircraft maintenance operations follow rules that go beyond the technical competence necessary for carrying out maintenance activities. In fact, an important characteristic of the first type of activities is the need for a intense fighting against the occurrence of human error when performing the task. This is due to the fact that an aircraft after maintenance can not be tested in the same way as other equipment, which is often placed on a workbench to be tested simulating flight conditions. However, this does not mean that human error is tolerated in the case of the component maintenance, but it means that the principles that guide its combat are more associated with the quality of the process rather than to the safety of flight. For that reason, as explained Cheung, Ip and Lu (2005), it is difficult to allocate specialized manpower among the various activities which compound aircraft maintenance. Also, from a broad point of view, it can be said that aircraft maintenance requires a managerial approach that goes beyond the management of technical dimensions.

Types of Aircraft Maintenance

The aircraft maintenance can also be classified as preventive maintenance (hard time and on condition), corrective maintenance or predictive maintenance (condition monitoring). (Knott, 1999).

The model shown in Figure 1 is a simplified view of the relationship between aircraft maintenance, with its three classifications, and the maintenance of aircraft components (items).

- Preventive Maintenance - To Tu et al. (2001), preventive maintenance is the practice of replacing components or subsystems before they fail, usually with frequency predetermined (hard time) or as a result of inspection and testing (on-condition). The goal is to maintain continuous operation of the aircraft system;
- Corrective maintenance - To Moayed (2009) is one that occurs after the identification and diagnosis of a problem. During this diagnostic service, technicians have to identify the parts that failed and have to perform repair actions;
- Predictive maintenance - Takes into account the continuous monitoring of the operating limits of a given component or subsystem. Whenever, it is found any clue about the occurrence of a functional failure, the component or subsystem must be removed for maintenance. Some mechanisms for the implementation of predictive maintenance are the NPC (Product Data Management) / PHM (Produc History Management).

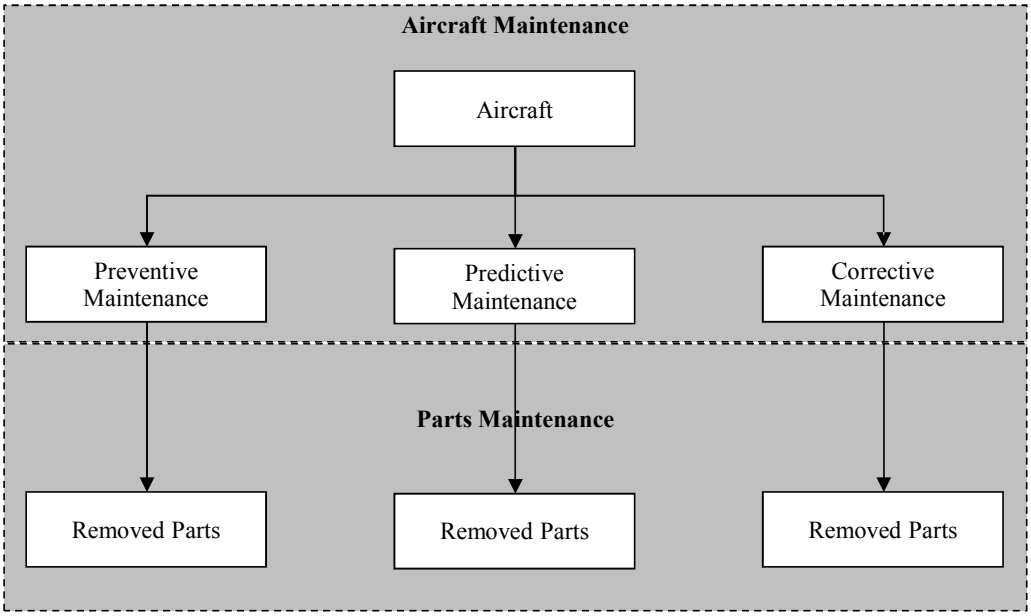

Figure 1 – Model aircraft maintenance

Regulatory environment of the Brazilian Aeronautics Maintenance

The mission of the National Civil Aviation Agency (ANAC) is to promote excellence in safety and civil aviation system, in order to contribute to the country's development and well-being of Brazilian society. Therefore, ANAC has the attribution of establishing and monitoring compliance with the regulatory framework governing the activities of the maintenance companies.

With regard to the activities of aircraft maintenance workshops, the FAA classifies companies according to the type of services they are able to perform. Thus, they can be

maintenance shops of aircraft, of cells, engines, propellers, rotors, of equipment and parts of such sets.

For those maintenance categories, ANAC also established patterns, classes and limitations for the maintenance activity. Therefore, any company that wants to be classified as an aircraft maintenance workshop should submit to ANAC a request for approval, specifying in which aircraft, engine, propeller, rotor, equipment or part it will perform the maintenance service. Based on the Brazilian Aeronautical Homologation Regulation - RBHA145 - are evaluated the technical and organizational capabilities of the company, which once homologated receives a Certificate of Homologation for Enterprises - CHE.

The requirements, set by RBHA 145, emphasize the importance of management for maintenance organizations. Despite this, as pointed out by Fedel, Borges, Santos and Soares (2006), nowadays, organizations linked to aviation are increasingly developing a culture of cost and expense reduction, in order to improve or recover their profit margins, while the development of an organizational culture focused on safety is not viewed with the same importance. The possibility of encountering such shortsighted managerial approach among aircraft maintenance companies reinforces the need to assess and better comprehend their management systems and the relative importance of their constitutive elements, in Brazil.

Methodology

In this research, it was used a survey methodology. The preparation of the questionnaire was supported by different sources of information, ranging from group discussions, personal interviews, and content analysis of textbooks and of standards for management systems. In addition, consultation was carried out in academic literature, in the field of aircraft maintenance, as well as in publications of the Brazilian Civil Aviation Authority (ANAC). Industry professionals participated through direct consultation or through presentations on seminars and congresses. The information obtained was used to develop an evaluation questionnaire that included various aspects of organizational management. The questionnaire was tested in four companies, and from the initial 80 questions, 21 were eliminated, due to their non-applicability for the case of aircraft maintenance, or because they were redundant, or even because their lack of relevance in terms of the research objective. The 59 remaining questions characterized the data collection instrument. However, it has to be pointed out that the full questionnaire included 66 questions, because it considered issues related to the description of the companies studied. The main focus of the set of questions was to identify the importance given to the different aspects of the maintenance management.

Table 1 – Characteristics of respondent companies

Characteristics of respondent companies	***Frequency***	***Percent***
Repair Station	16	72,7%
Airline	6	27,3%
Respondent -managerial level	15	68,2%
Respondent - technical level	7	31,8%
Over 100 employees	6	27,3%
Located in the Southeast Region	18	81,8%
ISO 9001 Certified	1	0,04%

The application of the questionnaires was discussed taking into account various possibilities such as website, postal mail, personal delivery and electronic mail. At the end, it was decided to send questionnaires by mail, because of the limited financial resources available for research and also because it was expected quick response. Based on data obtained from the Institute of Industrial Promotion and Coordination (IFI), there were selected all the aircraft maintenance companies that are inscribed in IFIs registry. Thus, for a sample of 148 companies the questionnaires were sent. Of this total, 39 companies could not be contacted due to problems in the data register. The findings are based on 22 questionnaires that were deemed complete and valid (18%). Although the response rate is low, the sample is representative of the entire population of companies registered in the IFI's database. The profile of the organizations that responded to the questionnaires can be seen in table 1.

The method

Aiming to evaluate the management systems of aircraft maintenance companies, in Brazil, with regard to their management practices, and to identify which managerial factors are taken into account by those companies, it was utilized the Factor Analysis method on the data obtained from the questionnaire. The exploratory factor analysis is a statistical technique for reducing data used to identify the internal relations among a set of correlated random variables (Green et al., 1973). Thus, when this technique is applied, you can define a set of easily interpretable linear combinations of the original variables called factors. Factor analysis was originally developed by Spearman (1904) to explain the performance of students in different courses and to understand the link between intelligence and qualities and became one of the techniques used by statisticians in psychological research. His basic premise was that the underlying factors could be used to explain such complex phenomena (Sharma, 1996).

In this work, data were analyzed using a principal components solution with factor matrix orthogonal rotation (varimax) for the factor analysis to ensure that the extracted factors are independent.

In order to determine the number of factors, an important rule is to use the eigenvalue as the cut-off value and maintain all factors with eigenvalues greater than or equal to one (the latent root criterion). The point at which the eigenvalues begin to flatten can also be used as a cutting point (Velicer and Jackson, 1990). However, perhaps the best method for an exploratory approach is to use the eigenvalue and cut-offs as general guides for the dimensionality of the space, and to allow that the interpretation of factors indicates the exact number of factors to be retained. According to Minhas e Jocobs (1996), the main limitation is that the analysis involves the assessment of subjective factor in determining the number of factors, as well as the interpretation of the factors themselves.

In this study, it was used, both, the factors interpretation, and the cumulative percentage of total variance extracted by successive factors, to determine the number of factors.

Results

The factorial analysis with varimax rotation was used in the set of 59 Likert type questions, in order to clarify the structure of underlying data. The initial solution of factors identified seven factors. Table 2 presents the obtained factor loading for each of the seven factors, as well as their explained variance. The first factor loaded heavily on the first 27 variables of this factor and it can be labeled as "Technical and Organizational Planning." This factor alone explained about one-fourth of the total variation in this solution. The second factor is highly correlated with the next 12 variables. Such factor can be called "Information Technology and Functional Structure."

This factor indicates that information technology and organizational structure are not seen as a priority element for the Brazilian companies management systems. The third factor can be called "Operational and Technical Documentation", because it has a high load in the next 7 variables that represent the control and handling of the documentation necessary to perform the maintenance. The fourth factor includes the next three variables, and was called "Human Factor and Content Certification". It reflects the position of management with respect to politics in human resource management. The fifth factor includes the following 4 variables and was named "Quality Assurance". The sixth factor has the following three variables load, and it was called "External environment, provision of services and materials," That factor deals with the positioning of the companies in relation to the procurement process. The seventh factor considers the last four variables and is associated with communication and control manuals. These seven factors accounted for 71.0% of the variance, as shown in Table 2.

Table 2 – Results of factor analysis of data relating to the management system.

	Factors						
Variables	1	2	3	4	5	6	7
Q09	***0,579827***	0,506054	-0,39115	0,242474	-0,14694	-0,05603	0,110523
Q10	***0,830837***	0,086433	-0,29117	-0,0932	-0,09865	0,295692	0,103367
Q11	***0,567897***	0,085655	0,022512	-0,45891	0,298552	0,095945	-0,05842
Q18	***0,731319***	0,343015	0,061522	0,121918	0,214351	0,131371	0,06621
Q20	***0,618859***	-0,18471	-0,17779	-0,0746	0,085866	-0,22411	-0,08734
Q21	***0,727056***	-0,1917	-0,48582	0,00143	0,2437	0,045914	-0,18321
Q22	***0,625503***	-0,32481	-0,11546	0,140779	0,060259	-0,27597	0,059963
Q27	***0,843059***	-0,05092	-0,26962	-0,21571	0,077363	0,140698	-0,06934
Q31	***0,645863***	0,442607	0,109236	0,325116	0,235795	-0,18521	0,145502
Q34	***0,653158***	0,532815	-0,09128	-0,17281	-0,02218	-0,07993	-0,12453
Q35	***0,661701***	-0,45626	-0,35614	-0,2958	-0,11367	-0,03868	-0,21489
Q36	***0,723118***	-0,01718	0,238686	-0,41881	-0,30532	-0,08535	-0,18073
Q37	***0,670782***	-0,22322	-0,13214	0,309375	0,155794	0,300989	-0,32052
Q38	***0,637988***	0,201204	0,125198	0,517623	-0,1941	0,136476	0,28801
Q39	***0,694635***	0,416569	-0,10144	-0,06368	-0,18528	-0,0317	-0,04053
Q40	***0,662948***	0,313992	-0,25985	0,076232	-0,16105	0,072344	0,035613
Q42	***0,572759***	-0,09446	0,451693	-0,14903	-0,01639	-0,15546	0,25642
Q46	***0,676644***	-0,15333	-0,39258	0,413763	-0,08376	0,297473	0,138341
Q48	***0,577338***	0,097215	0,423161	0,352659	-0,00549	-0,02411	0,164674
Q50	***0,686159***	0,365552	0,121204	-0,04065	0,253991	-0,1034	-0,01012
Q51	***0,611741***	0,332181	0,171527	-0,11579	0,190397	0,309516	0,106751
Q52	***0,692917***	0,236201	-0,42579	0,090889	0,081949	0,021899	-0,04597
Q55	***0,711786***	0,30797	-0,27198	-0,27584	-0,29023	-0,02248	-0,19388
Q56	***0,703458***	0,059834	-0,02044	-0,5145	-0,16741	-0,14097	0,065699
Q58	***0,640356***	-0,19367	0,0168	0,346245	0,087232	-0,03463	0,190595
Q59	***0,681997***	-0,33348	0,184919	0,233338	0,091967	0,008298	-0,04209
Q57	***-0,20365***	0,197947	0,030466	-0,00198	0,135976	-0,1062	-0,03889
Q08	0,182598	***0,401365***	-0,12835	-0,13487	-0,32267	0,276565	0,228201
Q14	0,400465	***0,422893***	0,252315	0,403218	0,255494	-0,21746	-0,10489
Q15	0,443557	***-0,72348***	-0,34738	0,070637	-0,0675	-0,0354	-0,03174
Q23	0,342007	***-0,74573***	-0,0974	0,064421	0,218215	-0,26742	0,124067
Q24	0,04828	***-0,47804***	-0,23582	-0,10608	-0,18054	-0,39073	0,349687
Q26a	-0,40547	***0,706623***	-0,16773	0,082245	-0,31682	-0,0244	-0,19299

Q26b	-0,48215	***0,684926***	-0,16675	0,106649	-0,23058	-0,04529	-0,1145
Q26c	-0,59762	***0,645636***	-0,06661	0,156174	-0,18175	0,034864	-0,13765
Q26d	-0,24329	***0,421642***	-0,32743	0,224797	-0,31094	-0,15113	0,369053
Q29	0,314398	***0,377365***	-0,09959	-0,24163	0,068829	-0,23049	-0,13693
Q30	0,352587	***-0,47943***	-0,26191	0,233609	-0,33177	-0,13663	-0,34361
Q53	0,453559	***0,45831***	0,249328	0,43483	0,078285	-0,12626	-0,14421
Q03	-0,3185	-0,06386	***-0,73032***	-0,02166	0,116489	0,132756	0,032513
Q05	0,256655	-0,06293	***0,543964***	0,484915	-0,04979	0,114669	-0,08909
Q16	0,468064	-0,32047	***-0,50707***	0,350954	0,127019	0,071196	0,049577
Q25	0,280725	0,012215	***0,586711***	0,54263	-0,10724	-0,08934	-0,2087
Q41	0,49358	-0,20859	***0,55358***	-0,27504	-0,18495	-0,03723	0,239476
Q43	-0,12823	-0,2407	***0,24944***	-0,20383	-0,30361	0,027057	0,218537
Q45	0,269006	-0,26463	***0,541763***	-0,20499	-0,48901	-0,22962	0,180613
Q54	0,447306	0,332989	-0,11933	-0,59133	-0,0528	0,071304	0,190132
Q02	0,088722	0,457638	0,286323	***-0,50927***	0,113933	-0,02881	0,257635
Q47	0,409817	-0,07205	0,456916	***0,521545***	-0,32539	-0,11598	0,139206
Q01	0,303425	-0,18529	0,307566	***-0,31467***	-0,43198	-0,25052	-0,36888
Q04	0,257697	0,281273	0,264706	-0,1542	***0,541105***	0,152487	-0,29959
Q26e	-0,29882	0,29534	-0,2133	0,086571	***-0,48684***	0,423531	0,330134
Q44	0,394329	-0,11502	0,483596	-0,24179	***-0,51025***	0,01614	0,165491
Q17	0,128026	-0,02626	0,057927	0,228253	***-0,50162***	-0,63085	-0,01952
Q28	0,276653	0,387334	-0,05041	0,067483	-0,2774	***0,45275***	0,358647
Q32	-0,04334	0,313779	-0,18539	0,153411	0,086925	***-0,77755***	0,165094
Q33	0,30095	0,423437	-0,19658	-0,44706	0,145299	***-0,57832***	-0,2012
Q06	-0,11831	0,150604	0,237932	0,205091	0,020639	0,029476	***-0,46404***
Q07	0,148952	0,380416	0,004723	0,025503	-0,4057	0,165549	***-0,52774***
Q19	0,212327	0,22609	-0,18801	0,192574	0,369886	-0,05096	***0,516445***
Q49	0,421488	0,25038	0,399328	-0,00281	0,142799	0,091993	***-0,46744***
Explained variance	24,4%	11,9%	9,6%	7,5%	6,7%	5,8%	4,9%

Total explained variance: 71,0%

The average of the factors for the analyzed set of data indicates that the companies surveyed considered that "Manuals and Technical Communication" (4.54) tends to be the most important factor in the management systems of enterprises maintenance when compared to other factors identified in Table 3. Although the scale to assess the management system of organizations have been developed and optimized by means of a pilot study, the relative importance of factors can be attributed to the nature and redaction of the questions.

Table 3 – Means and standard deviations for the factors

Factors	*Mean*	*Standard Deviation*
Organizational and Technical Planning	4,14	0,54
Information Technology and Functional Structure	3,78	0,91
Operational and Technical Documentation	4,11	0,89
Human Factor and Content Certification	3,67	0,96
Quality Assurance	4,46	0,42
External environment, provision of services and materials.	4,40	0,58
Manuals and Technical Communication	4,54	0,40

Given this, it seems the respondents consider the responsibility for safety more important than, for example, the human factor and content certification. Contrary to this, the international certifying bodies for aircraft maintenance companies have dedicated a great effort to prevent human error in maintenance (EURESPACE, 2003).

Conclusions

This study evaluated the management systems of aircraft maintenance companies in Brazil with regard to management practices and, based on a set of data, identified which managerial factors taken into account by these companies. To evaluate the management system for aviation maintenance organizations, an evaluation questionnaire was developed and optimized by means of a pilot study for each dataset. The data were subjected to factor analysis and the results seemed acceptable internal consistency. An interesting finding of this study is that the companies consider "Technical Manuals and Communication" to be the most important factor in the management system. This aspect needs to be further researched to verify if there are specific reasons for companies deem more importance to technical manuals and communication than to other factors. It is possible also identify which firms, in terms of average values, have dedicated management meet the requirements set out in the regulations for aviation maintenance companies. Another important revelation is that "Human Factor and Content Certification" obtained the lowest average, which apparently means the maintenance companies are against the best practices established by the international aviation. Finally, this study provided an overview of the management systems of maintenance companies in Brazil. Based on the results, it was concluded that the aircraft maintenance organizations need to review some management practices in order to align itself with international practice. At another level, more research is needed to deepen some of the issues raised in this study.

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