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ADVANCED PERIODIC MAINTENANCE SCHEDULING METHODS FOR AIRCRAFT LIFECYCLE MANAGEMENT

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ABSTRACT

This paper reviews existing methods and techniques addressing the problem of maintenance support throughout the life cycle for high value manufacturing products such as aircrafts. As part of this doctorate research the analysis of current methods of maintenance scheduling was conducted. In order to contribute to a more comprehensive solution, an advanced approach (algorithm) of periodic maintenance is presented. The authors believe that this approach will reduce the cost of maintenance of high value manufacturing products. The algorithm based on constraint programming methods is briefly presented and the future research directions are discussed.

Keywords: Information systems, maintenance and repair of equipment, maintenance cost, periodic maintenance scheduling methods, methods of constraint satisfaction problem, domain ontology

1 INTRODUCTION

The competitiveness of the aircraft is influenced by a number of factors, including the operating system maintenance and repair of equipment. Maintenance and repair of equipment is an operation or a complex of operations intended to keep an item in the proper condition when used for intended purpose, on standby, for storage and transportation (GOST 18322-78 1978). British Standard Glossary of terms (3811:1993) defined maintenance as the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function. European Federation of National Maintenance Societies may be defined maintenance, repair, and operations as, "all actions which have the objective of retaining or restoring an item in or to a state in which it can perform its required function. The actions include the combination of all technical and corresponding administrative, managerial, and supervision actions."

The increasing requirements for products quality and fluctuations in customer demand, as well as dynamic competitors impose significant requirements on the ability of manufacturers to provide customers with products in the required quantity, quality and for competitive price. From a purely industrial point of view, this means higher reliability of a company’s technological capacities and their constant availability at the peak of their features. Thus the importance of maintenance effectiveness considerably increases, as well as the whole set of a company's asset management processes (Becker *et al*. 2006, Scheer 1994).

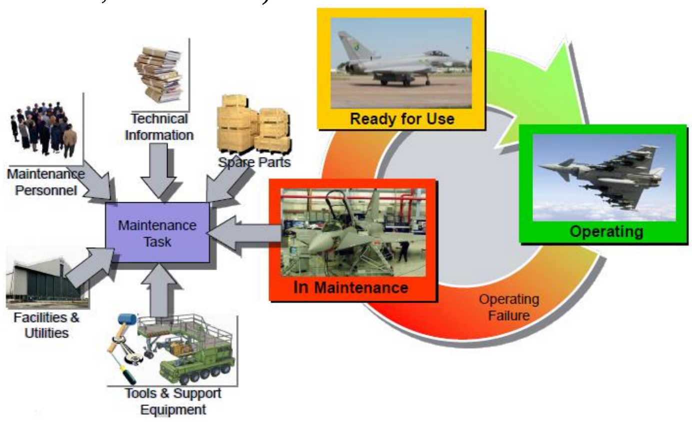

Figure 1: Maintenance, repair, and operations alignment to the service lifecycle. (c) Siemens AG, PLM Software Group

The main parameters that characterize the perfection of the maintenance system are the scope and frequency of maintenance work, which have a direct impact on operating costs and the intensity of the aircraft operation. It is obvious that the smaller the amount of work and the greater the frequency of their performance, the lower the operating costs and the stronger the aircraft operation. The share of the maintenance cost can vary from 10 to 50 percent of total operating costs, (Airline Maintenance Program Development Seminar, Fleet Maintenance Seminars, Boeing, Seattle, Washington, USA , 2008, Chapman 2006). The volume and frequency of maintenance affect The aircraft design features, the technical operation methods, regulatory and procedural requirements, the quality of work, operating parameters, environmental conditions and other factors influence on the scope and frequency of maintenance.

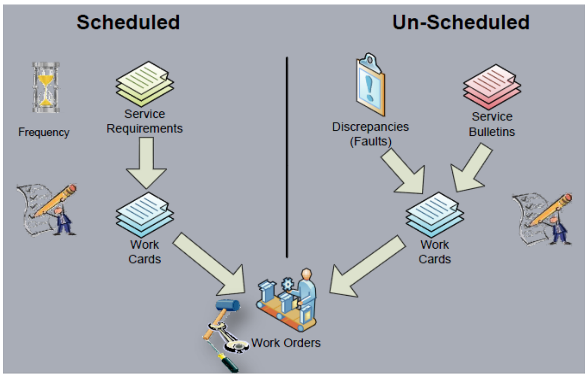

Figure 2: Scheduled and Un-Scheduled Maintenance. (c) Siemens AG, PLM Software Group

The scope and frequency of work are determined by the maintenance program. It should be noted that the requirements for the content of the maintenance program in Russia differ from those operating abroad. In the Russian Federation the maintenance program is a developer's document, common to the aircraft type, whereas the maintenance program abroad is a document developed by the operator for each individual aircraft taking into account the conditions and parameters of its operation and maintenance system adopted by the operator based on the minimum maintenance requirements specified in the process of type certification.

In this article methods of aircraft maintenance scheduling are considered.

2 MAINTENANCE SCHEDULING METHODS ANALYSIS

The objectives of an efficient airline maintenance program are:

- To ensure realization of the inherent safety and reliability levels of the equipment.

- To restore safety and reliability to their inherent levels when deterioration has occurred.
- To obtain the information necessary for design improvement of those items whose inherent reliability proves inadequate.
- To accomplish these goals at a minimum total cost, including maintenance costs and the costs of resulting failures.

These objectives recognize that maintenance programs, as such, cannot correct deficiencies in the inherent safety and reliability levels of the equipment. The maintenance program can only prevent deterioration of such inherent levels. If the inherent levels are found to be unsatisfactory, design modification is necessary to obtain improvement (ATA MSG-3 2007).

In the general statement in the presence of all the necessary initial information quantitative confirmation of maintenance program effectiveness is to provide a set of probabilistic aircraft safety performance, while minimizing maintenance cost (e.g., maintenance cost per flying hour). In this approach, the main difficulty is the quantitative confirmation of compliance with the aircraft requirements, which requires an adequate mathematical model allowing to assess the impact of maintenance on the aircraft safety and effectiveness.

Real alternative to the quantitative approach is the rational combination of quality engineering analysis of the choice of technical operation methods and the aircraft maintenance with a quantitative optimization of maintenance frequency on based on the mathematical model scheduled maintenance influence on the on-board systems reliability and safety. This allows to analyze the impact of possible system failures and their components on the aircraft flight safety, regularity and efficiency ("Applied Logistics" 2010).

A qualitative approach was proposed in the 70's by United Airlines and later became widely known as a guidance document on the development of a scheduled maintenance program - ATA MSG-3 (LII. MM Gromov, State Research Institute of Civil Aviation 2010). This document is recognized by the U.S. FAA, JAA and EASA European Union and is widely used by the aircraft developers and operators.

Practice shows that MSG-3 method has a number of drawbacks. MSG-3 principles have been refined and developed to Operator/Manufacturer Scheduled Maintenance Development (ATA MSG-3 2007), which engineers and service technicians can use to the create and maintain aircraft operation.
MSG-3 method of maintenance scheduling describes the method for developing the scheduled maintenance program. Non-scheduled maintenance results from scheduled tasks, normal operation or data analysis.

Maintenance programs will be developed via use of a guided logic approach and will result in a task-oriented program. The logic's flow of analysis is failure-effect oriented. Items that, after analysis, have no scheduled task(s) specified, may be monitored by an operator's reliability program. The method for determining the maintenance program for systems/powerplant, including components and auxiliary power unit, uses a progressive logic diagram. This logic is the basis of an evaluation technique applied to each maintenance significant item (system, sub-system, module, component, accessory, unit, part, etc.), using the technical data available. Principally, the evaluations are based on the item's functional failures and failure causes. Before the actual MSG-3 logic can be applied to an item, the aircraft's significant systems and components must be identified. This process of identifying Maintenance Significant Items (MSI's) is a conservative process (using engineering judgment) based on the anticipated consequences of failure (ATA MSG-3 2007).

In the Russian Federation this task is carried out by specialists of "Applied Logistics" Scientific Research Centre of CALS-technologies. They proposed a "Method of maintenance frequency choosing on the basis of quantitative evaluation methods". Scheduled maintenance frequency is set so as to minimize the natural deterioration of inherent aircraft safety and reliability, its systems and components, preventing the level of aircraft airworthiness from exceeding the established standards. Scope of the aircraft scheduled maintenance is determined by a working group comprising representatives of airlines and a developer and is submitted for approval. In determining the aircraft maintenance work frequency standard modes of operation are considered: The average model flight, the average plaque ("Applied Logistics" 2010, Sudov *et al.* 2006).

Nowadays maintenance program scheduling is based on product passport data, organization standards, industry requirements, etc. In this case, lead time is rigidly fixed on the time axis by assigning scheduled maintenance intervals. Maintenance intervals are set cyclically. The work scope at every maintenance is formed depending on its type. Each maintenance type is provided with a list of works given by the documentation to be executed as part of the maintenance. The main disadvantages of this method are: the inability to make changes to the maintenance program, lack of feedback from the servicing system, lack of data accumulation on the servicing system, low adaptive capacity.

Based on this analysis, the main goal of this research was defined as: to create a method and algorithm for improving scheduling of periodic maintenance actions (works) as universal maintenance procedures. This will greatly simplify the support of the whole system, expand the area of its use, and hopefully will reduce the maintenance cost of complex products (aircraft).

3 PROBLEM STATEMENT AND SOLUTION

Maintenance procedure is work scope $W_n = \{w_k\}$, where w_k is *k*-work, W_n is work scope, which is included in the maintenance P_n. Illustration of this fact you can see in the Figure 3.

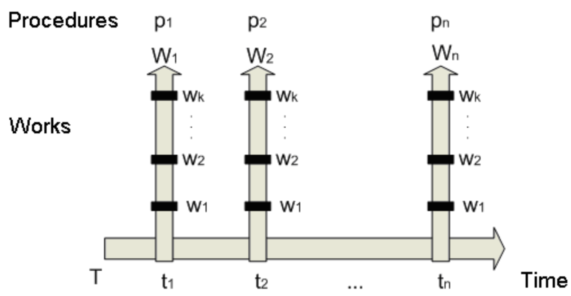

Figure 3: The task of maintenance scheduling.

The problem statement is the following: to define maintenance procedures work scope and time under which the selected criteria will take the extreme (minimum). For example, the selected criteria can be the following:

1. The maintenance total cost should seek to minimize: $S \to \min$, where S is the maintenance total cost;
2. Maximum procedure time of execution should seek to minimize: $R = \max(R_n) \to \min$, where R is maximum procedure time of execution.

The problem has to be solved taking into account special constraints. The special constraints can be the following:

1. Time period between the works must be less than or equal to the specified maximum time between the works;
2. If two works, determined by the compatibility matrix, are done in one maintenance procedure, their costs will be reduce by 20%.

A possible solution appear in the Figure 4.

N					1				
...			1					1	
7		1			1				
6									1
5				1					
4	1		1				1		
3						1			
2									1
1	1		1	1	1				
	1	2	3	4	5	6	7	...	K

Figure 4: A possible solution.

To achieve this goal we reduce the problem to the general problem of configuration design, which refers to the distribution of specific works among procedures.

There are two types of tasks on system configuration: selection and/or placement and hierarchy system. Our problem is the first type. Input: a set of elements/components, which is divided into subsets.

The essence of the constraint programming method is to describe a set of domain rules and constraints. Constraints may be presented in the form of equations, inequalities, logical expressions, etc.

Based on industry case studies and number of practical researches conducted with number of the aerospace companies we defined an advanced approach for improving the regular maintenance of complex, high value manufacturing products, described generally in number of stages:

- The functional decomposition of the work into a hierarchy of components and the composition of the work scope (maintenance/repair work domain ontology).
- Description of regularities determining the inclusion of this work in the periodic maintenance as constraints.
- Starting a mechanism to monitor the resulting complex maintenance work based on constraint satisfaction programming (CSP) (Rossi *et al*. 2006). The last stage consist of 3 sub-stages:

First sub-stage: satisfaction of the constraints that are associated with the known parameters of the components. Method NC-1 (Benhamou *et al*. 1997, Cleary 1987).
This algorithm allows to remove all the values that do not satisfy the unary constraints from all the domains of the problem variables.

Consistency in the nodes is achieved by viewing each item in each field and checking whether it satisfies the value of the unary constraints on that variable. All values that violate the unary constraints are removed from these domains.

Having completed the algorithm, the initial problem is reduced to the task, which is consistent in the nodes.

Second substage: the pairwise comparison of directory components, which is aimed at removing the components not compatible with each other. Method of pre-screening Forward Checking (Gent Ian, Bartak).

Using the method of Forward Checking the search space can be significantly reduced or completely resolved (Benhamou *et al*. 1997, Cleary 1987).
The basic idea of the method can be expressed as follows: if the set of inequalities becomes inconsistent while assigning the domain value to a variable, inconsistent values should be removed from the domains of the other variables. After that the search can be continued. In case the current domain is empty there is roll back to the previous level (Gent Ian). Domain is a set of components (works) from the directory.

The search should be started with the variables that have domains with the least number of values.

Third substage: the calculation and verification of compliance with the requirements of the design parameters. Backtracking method (Dechter *et al.* 2002).

Backtracking algorithm for solving constraint satisfaction problems (CSP) is compiled on the basis of a recursive depth-first search (Dechter *et al.* 2002, Semenov 2003).

This method involves the enumeration of all possible combinations by traversing the tree layout options with returns in case of the constraints are not satisfied, as shown in the Figure 5.

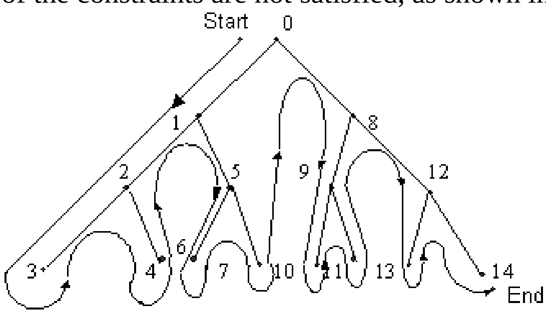

Figure 5: Backtracking.

The method allows to perform a full search of all the components combinations, and to find all possible solutions.

4 CONCLUSIONS AND FUTURE WORK

In this study, an analysis of existing methods of maintenance scheduling was presented. The key challenges and opportunities were defined. Advanced approach (algorithm) for periodic maintenance were described. The algorithm is based on constraint programming methods. The next step will be a creation of practical case studies for specific industry (aerospace industry) which will enable us to evaluate the effectiveness of the proposed framework. Also, cost reduction analysis (Taratoukhine *et al.* 2002, Becker *et al.* 2007) will be conducted to evaluate economic effectiveness of the proposed method. Finally, integration of the proposed solution to current ERP/EAM systems as joint co-innovation program between Bauman Moscow State Technical University/ERCIS Lab Russia and SAP will be considered.

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