Design of Real-time Auto-grouping Algorithm for Maintenance Tasks of Civil Aircraft

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Keywords: Maintenance task, Task interval, Man hours, Task grouping.

Abstract. This paper aims to solve the problem of how to use computer to realize the real-time control and management of maintenance tasks packet, so as to improve the work efficiency of maintenance managerial personnel. The paper chose B737NG series aircraft maintenance tasks as the object of study. Firstly, it analyzed the attributes of maintenance tasks, and selected task number, task intervals and man hours as main attributes. Next, according to the conversion rules in AC-121-53, task intervals with different usage parameters were unified into the same usage parameter. Meantime, the regulations of the maintenance interval deviation from AC-121-53 were viewed as the basic restrictions of maintenance task grouping. Then, the real-time auto-grouping algorithm was obtained. Finally, the example was given to verify the result and compared with actual inspection packet of a certain airline. The results show that the algorithm can overcome the shortcomings of artificial packet and improve the efficiency of grouping.

Introduction

With the vigorous development of domestic civil aviation industry and the continuous expansion of the fleet size of major airlines, the amount of aircraft maintenance tasks also shows an explosive growth trend. Compared with the increasing number of maintenance tasks, the 121 units of civil aviation are still relying on manual work to group maintenance tasks for the scheduled check and work out the short term maintenance plan. Each maintenance task will be one-to-one correspondence with a maintenance work card, and the maintenance task will be issued and implemented in the form of work card [1]. The number of maintenance work cards for airlines to finish amounts to more than ten thousand, and the maintenance management level of airlines is still limited. Based on the above reasons, the wrong arrangement and omission of maintenance work cards occur now and then [2]. The real-time control management issue of maintenance tasks has become a problem that cannot be ignored in the development of all 121 units. The 121 unit is the carrier of large aircraft public air transport. According to the provisions of CCAR-121, all of the airlines belong to the 121 units which must ensure that the implement of maintenance work should comply with the maintenance requirements of the relevant civil aviation regulations of china. Although domestic and foreign scholars have begun to pay attention to the problem of aviation maintenance production planning and maintenance task real-time control [3-7], the published articles are relatively few, and fewer articles are available to aim at solving the practical problem about maintenance task real-time package control for airlines.

The current situation of maintenance task management that commonly exists in airlines is that most of them depend on the aircraft maintenance information management system which is developed by themselves or purchased from third party to monitor and early warn the executive time of maintenance tasks [8]. And then the tasks that can be executed together are packed into a work package by the management staff and sent to the maintenance engineering department to carry out. At the same time, since Boeing and Airbus have removed the concept of letter check (which is a kind of
management pattern of the maintenance task, such as A check, C check and D check) from the
documents such as MRBR and MPD, the maintenance intervals of all tasks are given separately [9],
which poses a greater challenge to the maintenance management level of the airlines. But currently
most airlines are still accomplishing the maintenance program according to the way of past, that is,
letter check.

The purpose of this paper is to put forward a practical and feasible plan to pack the maintenance
tasks into groups automatically according to certain rules. Thus, the working pressure of the staff who
are responsible for maintenance task management can be greatly alleviated, the heavy workload of
manual task scheduling can be reduced. The working efficiency and accuracy rate of maintenance
task grouping, meanwhile, can be improved.

Maintenance Task Analysis

Sources of Maintenance Task

The sources of most maintenance tasks mainly incorporate Maintenance Review Board Report
(MRBR), authorized by the administering authority of the aircraft manufacturing country,
Maintenance Planning Document (MPD), provided by the aircraft manufacturer, and Maintenance
Program (MP), made by airlines based on the condition of their own fleet. The three files contain
most of the same maintenance tasks, but there are some differences in the attributes of the
maintenance tasks they given. Taking the maintenance task which is numbered as 20-010-01 in the
second chapter (system/power plant maintenance program) as an example, the contents of this task in
the above three documents are given in Fig. 1-3.

![Figure 1. Maintenance Review Board Report (MRBR).](image1.jpg)

![Figure 2. Maintenance Planning Document (MPD).](image2.jpg)

![Figure 3. Maintenance Program (MP).](image3.jpg)

By comparison, we can see that the maintenance task attributes contained in the Maintenance
Planning Document (MPD) are the most comprehensive, almost including all of the attributes given
by MRBR and MP. Therefore, the 2012 version MPD that goes for Boeing’s 737-600/700/800/900
serious aircraft is chosen as the source of the data in this paper.
Attributes of Maintenance Task

The attributes of maintenance task that given by the Maintenance Plan Document (MPD) consist of MPD Item Number (Task number), AMM Reference, CAT (Failure-effect category), Task (MSG-3 task category), Interval (Threshold and Repeat), Zone, Access, Applicability APL and ENG), Man-Hours, Task description.

Among them, all tasks listed in the CAT section have a category identification as follow: 5-evident, safety; 6-evident, economic (operational); 7-evident, economic (non-operational); 8-hidden, safety; 9-hidden, non-safety. MSG-3 task categories mainly include LUB (lubrication), SVC (servicing), OPC (operational check), GVI (general visual inspection), FNC (functional check), RST (restoration), DIS (discard), and so on.

In the following study, the main task attributes that will be used are task number, task interval and man hours.

Task Number of Maintenance Task

Each maintenance task from MPD [10] is given a unique task number (MPD item number) which generally consists of seven Arabia digits and two short lines. The first two digits are the ATA chapter number (for example, chapter 24 is about electrical power and chapter 34 is about navigation). The third to five digits are the MPD sequence number. And the last two digits represent MPD position number (digits ‘00’ refers to regardless of left and right, digits ‘01’ refers to left, and digits ‘02’ refers to right).

Interval of Maintenance Task

Maintenance task intervals are specified in terms of a frequency value and a usage parameter such as FH (airplane flight hours), FC (airplane flight cycles), calendar time, AHR (APU hours), APU CNG (APU change) and so on. All of the above, FH, FC and calendar time are the most frequently used parameters. Calendar time includes YR (year), MO (month) and DY (day). As mentioned in the introduction, letter checks are not used in the MPD. As shown in Fig. 4-6, the maintenance tasks with different usage parameters in MPD are given.

Man Hours

Man hours refer to the estimated working hours required for each aircraft to complete each maintenance task. These working hours do not include the time required to gain access, position work.
stands, defuel and purge fuel tanks, troubleshoot, nor correct discrepancies found while performing the maintenance task. The man hours are estimated based on the use of skilled personnel and ready availability of required tools and equipment.

The man hours of maintenance tasks are very important parameters for making the production plan. It is very useful and necessary for airlines to calculate the total man hours required by the work packages and the total man hour can be used as an important reference for the allocation of maintenance resources. At the same time, by comparing the actual working hours with the theoretical working hours, the efficiency of maintenance personnel can be evaluated, and the utilization rate of personnel can be improved.

Data Pre-processing

Because the intervals of maintenance tasks are given by different usage parameters, the interval of different parameters cannot be calculated directly. Therefore, in order to facilitate the calculation, first of all, it is necessary to unify the usage parameters of the task intervals according to certain transformation rules. In this paper, the usage parameters of all maintenance task intervals will be uniformly converted to FH (flight hours). By analyzing the time conversion rules of the newly added aircraft provided by the AC-121-53 (Advisory Circular) [11] in the sixth chapter fifth section, we can obtain the specific time conversion rule as follows.

\[ \text{Conversion between Flight Hours and Flight Cycles} \]

First of all, we should be aware of the following concepts. The whole course of a take-off and landing of an aircraft is called to be a flight cycle, namely FC. The hour segment ratio of aircraft operation (also called cycle ratio) refers to the average number of flight hours per rise and fall (also called cycle), namely the ratio of flight hours to flight cycles. Therefore, we can conclude that the hour segment ratio is equal to FH divided by FC (cycle ratio = FH/FC). Then the transformation relation between flight hours and flight cycles is obtained.

\[ \text{FHs} = \text{FCs} \times \text{cycle ratio} \]

Conversion between Flight Hours and Calendar Time

Since the year and month can easily be converted into days (DY), thus we only discuss the conversion rule between flight hours and days (DY). The daily utilization rate of an aircraft refers to the flight hours per day of the aircraft, and the unit is hours/day. Since the daily utilization rate of each day or each aircraft is different, and this is not the focus of this paper, thus, we use the average daily utilization rate to simplify the following calculation. The average daily utilization rate refers to the flight hours of each aircraft per day in a fleet during a period of time.

\[ \text{FHs} = \text{DYs} \times \text{daily utilization} \]

Here, the paper only discuss the normal conditions, excluding the special conditions, such as the aircraft under low utilization.

Deviation of Maintenance Interval

Similar to the familiar letter check (A check, C check and D check), the paper chooses T as the basic cycle of the maintenance task package. Let it supposed that the maintenance engineers will implement maintenance tasks of aircraft systems and components at the time points: 1T, 2T, ..., kT (k ∈ N), which requires the maintenance task interval of each single component to be adjusted to integer times of cycle T, so that some maintenance tasks can be concentrated together to finish, that is to complete the packing of the maintenance tasks.

According to the regulations for deviation of maintenance program in the Bureau document AC-121-53, in the reasonable maintenance plan, the airline operator can complete the maintenance
tasks with time intervals specified by the Maintenance Program in advance, but the next time of the next completion of the maintenance task should be calculated from the time ahead of completion.

In reasonable unforeseeable circumstances, causing that the maintenance task cannot be carried out on time according to the scheduled maintenance plan, under the approval of the chief engineer of the operator, the actual interval of maintenance task to be carried out can be deviated from the interval specified in the airline’s Maintenance Program in the following range (except for the maintenance task from Airworthiness Limitations Item and Certification Maintenance Requirements, from which the task’s interval cannot be deviated).

Items controlled by flight hours:
(a) The maintenance interval within 5000 flight hours (including 5000) can be deviated with a maximum deviation of 10% of the specified interval;
(b) The maintenance interval of more than 5000 flight hours can be deviated with a maximum deviation of 500 flight hours.

After the occurrence of the above deviation, the next time to perform the maintenance task is calculated from the expiration time given in the Maintenance Program, not from the actual operating time. And after any deviation, it cannot be continuously deviated again.

As mentioned in the previous section, the usage parameters of maintenance intervals are unified into flight hours in order to facilitate subsequent calculations. Therefore, in this paper, only the deviation regulation of the maintenance task given with the parameter of flight hour is given.

**Design of Automatic Grouping Algorithm for Maintenance Task**

Before the design of the algorithm, the assumption is as follows. The maintenance resources (such as air material, equipment and tools, maintenance site, maintenance technicians, etc.) can guarantee the completion of maintenance tasks. Thus in the maintenance task grouping algorithm design, there is no need to consider the constraints of the above resources.

The purpose of the algorithm presented in this paper is to obtain a series of working packages, taking T as the cycle and including several maintenance tasks, namely 1T working package, 2T working package, 3T working package, ..., and so on. Then the execution time of the k-th ‘T check’, namely ‘Tk check’, is given by the Eq. 3.

\[ t_k = T \times k \]  

Among them, \( k = 1, 2, 3, ..., C \). The constant C here is the number of the working packages that we want to set out.

Suppose that there are N maintenance tasks, the first inspection interval of the j-th maintenance task is \( T_j(0) \), and the repeated check interval of it is \( T_j \), then the execution time of the i-th repeated inspection is given by the Eq. 4.

\[ t_j(i) = T_j(0) + T_j \times i \]  

Among them, \( i = 1, 2, 3, ..., M \). And, \( J = 1, 2, 3, ..., N \). Here the constant M is a larger positive integer.

The distance (absolute error) between the two above variables can be derived by the Eq. 5.

\[ \text{error}(i) = \text{abs}(T_k - t_j(i)) \]  

According to the following Eq. 6, the minimum error of a series of absolute error values can be found out, of which the corresponding subscript is set to be constant h.

\[ \text{error}(h) = \min \{ \text{error}(i) \}, \quad h \in i \]  

Then the execution time of the h-th repeated inspection of this j-th maintenance task is given by the Eq. 7.
\[ t_j(h) = T_j(0) + T_j * h \] (7)

If it accords with the deviation rules in the fourth section above, the j-th maintenance task can be included in the K-th T check, namely included in the Tk working package. The total man hours of the Tk working package is obtained by summing up the corresponding man hours of all the maintenance tasks which are qualified. And the total man hours can reflect the total workload. The general program flow chart of the algorithm is shown in the Fig. 7.

![Figure 7. General program flow chart of the algorithm.](image)

In the above flow chart of the automatic grouping algorithm, how to judge whether the j-th maintenance task is included in the k-th T check working package becomes the core part of the algorithm, and the function of this part mainly follows the deviation rules of the relevant maintenance task interval given in AC-121-53. The judgement rules of this logic part are as follows:

1) Firstly, judge the size of \( t_k \) and \( t_j(h) \), and then find the remainder of the larger to the smaller;
2) Secondly, compare the size of 5000FH and the maintenance interval of the j-th maintenance task. If the former is bigger than or equal to the latter, the third step is carried out; otherwise, the fourth step is taken;
3) Thirdly, compare the size of the remainder got in the first step and the ten percent of the j-th maintenance task’s interval. If the former is less than or equal to the latter, it can be concluded that the maintenance task J is included in the work package;
4) Fourthly, compare the size of the remainder got in the first step and 500FH. If the former is less than or equal to the latter, it also can be concluded that the maintenance task J is included in the work package.
The flow chart of this logic part is shown in the Fig. 8 below.

![Flow chart of logic part](image)

Figure 8. Flow chart to determine whether a task is contained in a work package.

**Algorithm Simulation Verification**

**Experimental Data Processing**

As shown in Fig. 9, according to the reference value given in the MPD, the value of the hour segment ratio is 1.8, the average daily utilization rate of the aircraft is 9 FH/day. And the value of the cycle T is 810 FH, that is the cycle of the A phase inspection.

![Reference values given in MPD](image)

Figure 9. Reference values given in MPD.

As mentioned in the 2.1 section, this paper selects the 2012 version MPD that goes for Boeing’s 737-600/700/800/900 serious aircraft as the source of the maintenance tasks. According to the characteristics of the maintenance tasks, 55 representative maintenance tasks (part of data are shown in Table 1) are chosen as the experimental samples, so the constant \( N = 55 \). In addition, we need to set the value of constant \( C \), which refers to the number of working packages we want, and the value of constant \( M \), which can be set to a larger positive integer. In this paper, we want to get 16 A check working packages from A1 to A16, so constant \( C = 16 \). And \( M \) takes 100.

<table>
<thead>
<tr>
<th>Task NO</th>
<th>Threshold /FH</th>
<th>Repeat interval /FH</th>
<th>Man-hours (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21-010-00</td>
<td>7500</td>
<td>7500</td>
<td>0.10</td>
</tr>
<tr>
<td>21-015-00</td>
<td>6000</td>
<td>6000</td>
<td>0.25</td>
</tr>
<tr>
<td>21-020-00</td>
<td>8000</td>
<td>8000</td>
<td>0.10</td>
</tr>
<tr>
<td>21-030-00</td>
<td>8000</td>
<td>8000</td>
<td>0.10</td>
</tr>
<tr>
<td>21-040-00</td>
<td>7500</td>
<td>7500</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Experimental Result and Analysis

By using the MATLAB software to simulate the real-time auto-grouping algorithm put forward above, we can obtain the details of the working packages, including which maintenance tasks are involved in and the total man hours of the package, that is, the amount of the tasks. After running the program, a serious of working packages, A1, A2, A3, ..., A16, are obtained. And the man hours of each one are \{ 5.9, 4.9, 4.42, 3.5, 1.65, 4, 1.77, 1.65, 4.2, 4.37, 3.1, 2.9, 2.37, 1.25, 6.8, 4.6 \}. The Fig. 10 below gives the contrast histogram of the total man hours required to perform the above 16 different A check packages.

![Figure 10](image)

Through the comparison chart, we can know the distribution of the amount of maintenance tasks at each time point, so as to arrange the maintenance personnel and other maintenance resources ahead of finishing the schedule.

This automatic packet method can greatly improve the efficiency of the pattern of manual packet, and avoid the possibility for the wrong arrangement and omission of maintenance work cards caused by the human factors.

According to the package rules of an airline in China, the abstract model diagram of MTOP (Maintenance Task Operating Plan) shown in Fig. 11 is obtained. By this way, the man hours of even times A inspection is larger than that of odd times A inspection, and the more obvious to the later stage. This leads to a great increase in aircraft stopping time and a decrease in utilization of aircraft.

![Figure 11](image)

By comparing Fig. 11 with Fig. 10, the automatically real-time packet algorithm presented above can effectively control the scale maintenance working package and aircraft parking time, making
more maintenance tasks to be done at the post-flight check. Thus it can not only improve the utilization of aircraft and the enforceability of the plan, but also can alleviate the surge phenomenon of maintenance task quantity in the later stage of aircraft usage to some extent.

Conclusions

The real-time auto-grouping algorithm of the maintenance task put forward by the paper has the function to automatically group the maintenance tasks in accordance with the Bureau documents, and to suggest a long-term maintenance operating plan. Through comparing the workload at different time point, maintenance personnel can arrange the maintenance resources in advance, such as air material, equipment and tools, maintenance site, maintenance technicians, and so on. The result of working package can provide assistant decision support for the staff of the production planning department when they are making the maintenance plan.

There are still some shortcomings in the real-time auto-grouping algorithm. In order to reduce the parking lot time, as many maintenance tasks as possible will be put into the route maintenance of the flight, taking up the time resources after the flight and shortening the parking time of the scheduled inspection. The time after the flight is usually about six to eight hours, in addition to completing the basic post-flight tasks (service and cleaning), but also can add some scheduled inspection tasks. Therefore, to group a specific size of the working package is necessary. In addition, the above algorithm is based on the ideal condition. In order to be closer to the actual situation, the next study can also join the limitation of maintenance resources.

References

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