Current Practices and Problem Areas in Aircraft Maintenance Planning and Scheduling – Interfaced/Integrated System Perspective

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Abstract. Aircraft maintenance planning and scheduling constitute planning, control and execution of materials (spare parts), operations (inspection, disassembly and assembly activities) and resources (labour, machines, transport equipment, etc.). This is a complex problem due to large number of components involved at various planning and execution levels, and the size/nature of resource-intensive maintenance projects. This paper reports current practices, problem areas and issues in aircraft maintenance planning and scheduling using both interfaced and integrated systems, based on a case study. The case study involves one airline in the region and an industry solution for aircraft maintenance planning and scheduling. Problem areas and issues within interfaced systems are reported, based on the selected airline while issues and potential improvements on the selected solution are identified based on a numerical study. Testing of maintenance planning and scheduling, based on maintenance order cycle within maintenance project, show that planning and scheduling methods in the industry solution can be enhanced by eliminating weaknesses of individual techniques involved. The paper concludes that key improvement areas on the planning and scheduling processes within an integrated system environment are simultaneous planning of materials, operations and resources involved, forward planning of operations/tasks, and finite loading of resources. Potential benefits from improvements include reduction in spare-parts inventory, shorter turn-around times and cost reduction in overtime.

Keywords: Heavy Maintenance, Forward Planning, Simultaneous Planning, Finite Capacity Planning.

1. INTRODUCTION

The aircraft maintenance involves repairing or replacing failed or failing components to keep the aircraft operational. Further, it is a complex task and is grouped into various categories: heavy maintenance, engine maintenance, line maintenance, component maintenance and configuration management. Maintenance planning and scheduling require managing a complex system (an aircraft) and processes for planning, control and execution of maintenance projects with many components across large spectrum of maintenance situations such as C-checks in heavy maintenance. Heavy maintenance planning, control and execution processes are driven by appropriate maintenance responses at various levels for each aircraft system. These responses may involve scheduled maintenance, inspection or repair-on-failure.

Overall, aircraft maintenance is a high cost activity, in terms of capital equipment down-time and spare-parts inventory (Friend, 1992; Nowlan, 1972). Not surprisingly, therefore considerable efforts have been made to develop systems that can minimise down-time, by more effective planning and control of maintenance and by endeavoring to use forward planning to predict spare-parts usage and overhaul requirements. Many early systems were individual functional applications such as Material Requirements Planning (MRP), Project Management (PM), Manufacturing Resource Planning (MRPII), etc. and were interfaced for overall planning and scheduling purposes. These functional applications are usually available in ERP systems as modules, based on cross-functional processes supported by a single database. However, ERP solutions with generic functional applications do not provide full functionalities for planning and scheduling of aircraft maintenance projects, using those modules. Recently, ERP vendors attempted to extend generic ERP systems to cater for specific functionalities required for planning and scheduling of aircraft maintenance projects across a broader spectrum including heavy maintenance, line.
maintenance, engine maintenance and component maintenance. One of such solutions is MRO (Maintenance, Repair and Overhaul), which is an industry solution for aircraft maintenance planning and scheduling and is provided by a leading ERP system vendor.

The maintenance management, in the organizational setting using an integrated system, can be considered as a multi-level process, which is modeled in abstract at higher levels and becomes increasingly detailed at lower levels. At the upper levels of a company’s management structure, the actual formulation of the company’s long-term maintenance strategy is carried out, which involves provision of maintenance resources and selection of a maintenance policy. At progressively lower levels of management, the maintenance strategy is realized and implemented. Within the hierarchy of the maintenance management, there are various maintenance types, strategies, techniques, methods, and associated problems and issues. Managing such a complex process across various levels, using an integrated system, can involve complex procedures, steps, transactions, huge amount of data and information.

The purpose of this research is to critically review those aspects of maintenance, with particular reference to use of both interfaced systems and integrated system (industry solution) for aircraft maintenance. In this research, maintenance issues in the aerospace environment are investigated with special reference to heavy aircraft maintenance planning and scheduling. Current practices of aircraft maintenance planning and scheduling using interfaced systems are identified, based on preliminary study of an airline in the region. Best business practices and integrative aspects of the industry solution for this complex problem replacing traditional interfaced systems are reviewed. Problems and issues in an integrated system environment are identified, in terms of various shortcomings and in-capabilities of current processes and associated methods/techniques. It also aims to identify possible improvements on planning and scheduling processes and potential benefits of those improvements when implemented in an integrated system environment.

This paper is structured as follows. First, the research methodology is outlined. This is followed by an overview of maintenance issues in the aerospace environment. This section provides an overview of the maintenance problem, current practices, problems and issues in the interfaced system environment. As this research proposes possible improvements on planning and scheduling processes in the integrated system, the next section provides an overview of the selected industry solution for aircraft maintenance, repair and overhaul (MRO). Problems and issues in an integrated solution environment are highlighted in the following section, with special reference to maintenance order scheduling, infinite capacity planning and functional deficiencies. Improvements for planning and scheduling processes within the selected solution are presented next. This is followed by a section on improvements and potential benefits to users of the industry solution when proposed improvements are incorporated into the integrated system. Finally, the paper concludes with findings and future research directions.

2. METHODOLOGY

In general, there are number of research methodologies discussed and adopted in empirical research. Scudder and Hill (1998) identified three ways of data collection: (i) use of case studies, (ii) use of surveys or interviews, and (iii) use of a panel of experts. The method proposed by Flynn et al. (1990) suggests a theoretical foundation for the research, which underlines the problem being studied, is established in the first stage. An appropriate research design suitable for both the problem and theoretical foundation is then selected. Although surveys are common in empirical research on broader production and operations management, a number of other designs including single and multiple case studies and focused groups, may also be used, depending on the problem being studied.

In this study, empirical research approach, based on a selected airline and an integrated system for aircraft maintenance planning and scheduling, was adopted. Problem areas and issues in interfaced systems, identified earlier as part of preliminary study (internal research report) aimed at developing an integrated solution for aircraft maintenance planning and scheduling (Samaranayake et al., 2002), are reported here, as a case study of interfaced systems. As part of the research analysis, the research problem is formulated, based on the literature review and the current status of interfaced systems and integrated solution on many aspects of planning and scheduling in aircraft maintenance. In the first part of the research, issues and problem areas in the aircraft maintenance planning and scheduling are investigated, based on interfaced systems of the selected airline in the region, followed by detailed analysis of a selected integrated solution for aircraft maintenance planning and scheduling. Numerical testing of planning and scheduling using the integrated systems is carried out, based on a set of master data created for testing.
maintenance order cycle within a large maintenance project. Improvements, potential benefits to customers through those improvements are identified, based on overall problem areas in both interfaced and integrated systems. The methodology proposed for those improvements is currently being developed and will not be discussed here, since it is beyond the scope of this paper and more importantly the confidential nature of the project.

3. MAINTENANCE ISSUES IN THE AEROSPACE ENVIRONMENT

3.1 Overview of Aircraft Maintenance Problem

Generally, commercial aircraft maintenance consists of number of potential problem areas, such as hanger scheduling; heavy maintenance planning and scheduling; line maintenance, component maintenance and engine maintenance. Scheduling a number of aircraft for maintenance at various levels is a huge task for the airline industry because much of this maintenance involves planning, control, and execution of large number of components such as materials (spare parts), operations (both assembly and disassembly), resources and suppliers. As a result, those maintaining aircraft are confronted with a large number of secondary problems, including:

- Large maintenance project networks involving a large number of activities,
- A large number of components and different maintenance levels,
- Integration of materials planning, operations and resources scheduling, and project planning,
- A large number of configurations for a generic aircraft structure,
- A huge amount of data and information in number of systems, and
- Large percentage of unplanned maintenance activities.

These problem areas, noted above, can be categorised into following main areas of planning, control and execution:

- Heavy maintenance
- Line maintenance
- Engine maintenance
- Component maintenance
- Configuration management

Of all categories above, heavy maintenance is considered to be the most complex problem due to involvement of planning and scheduling of large structures and many components. It also leads to other problems such as configuration management and component maintenance. Within the heavy maintenance, two main areas of research include:

I. Overall maintenance scheduling (commonly known as service scheduling) which involves hanger scheduling for a fleet of aircraft,

II. Detailed scheduling of components including materials, resources, operations and maintenance activities.

There were few earlier research publications on overall maintenance scheduling (category I above), including one carried out by Bird (1976), specifically aimed at the Qantas Maintenance division. Bird investigated a particular aircraft-scheduling problem where all maintenance was performed at one location. His study attempted to solve the scheduling problem using linear programming approach. Bird suggested that the feasible allocation of an aircraft to rotation required knowledge of the aircraft’s arrival time, current configuration and the hours flown since the last various maintenance checks carried out on that aircraft. As a result, whenever an aircraft was allocated to a rotation or underwent a maintenance check or configuration change, the appropriate state variables of that aircraft had to be updated.

Elkodwa (1996) provided another approach to flight and maintenance scheduling. The approach was based on heuristic methods to find a near-optimal solution for scheduling of a number of aircraft for maintenance. Smallwood (1988) suggested that aircraft maintenance be done every N days and N differs for each maintenance category. Although airlines had to maintain the planes before N days had passed, maintaining them earlier moved the next deadline forward. Smallwood (1988) studied two generic scheduling problems: The Multiprocessor Scheduling Problem (MSP) and the Green Time Scheduling Problem (GTSP) where GTSP was a hybrid of the airline maintenance problem. Both of these scheduling problems were formulated as integer programming formulations. Sherif (1980) developed algorithms and techniques to be used in a general way to handle optimization of various types of inspection and maintenance schedules of systems subject to stochastic failure. The optimal maintenance schedule incorporated the effects of inspection, maintenance, delayed detection, uptime and downtime costs. The techniques of differential calculus and dynamic programming were applied to the development of the optimal maintenance schedule.

More recently, Cheung et al. (2005a) proposed an aircraft service scheduling model using genetic algorithms. Their model was based on the application of an intelligent
engine to develop a set of computational schedules for the maintenance vehicles to cover all scheduled flights. However, the model does not allow for scheduling of resources directly associated with the maintenance of aircraft.

All of the reported literature above was the work carried out in the area of overall scheduling of the fleet or scheduling of resources outside the main resources involved in the aircraft maintenance. Further, there is minimal planning and scheduling of materials, activities, resources and suppliers involved in detailed scheduling of aircraft maintenance. However, there had been few attempts towards solving the problem of detailed scheduling of aircraft maintenance.

Brosh et al. (1975) categorised the management of maintenance into two categories: mathematical and engineering approaches. The mathematical approach was largely concerned with the development of optimal models for maintenance initiation using statistical methods to analyse the failure behavior of components. The engineering approach had a more heuristic orientation and was concerned with formulating an acceptable (not necessarily optimal) set of maintenance tasks that could be justified and realistically achieved. In general, the engineering approach provided a truer reflection of the actual maintenance process and hence was more widely employed in industry (Rommert, 1996). The difficulty of developing analytical models for interdependent components meant that the mathematical approach was mainly limited to providing optimal solutions for the failure of individual components (Vergin and Scriabin, 1977). However, there were numerous engineering approaches (Kelly, 1984; Gits, 1987; Moubray, 1992) that at least attempted to address the interdependence of arbitrary numbers of components when managing maintenance.

Further, few models had been developed to describe the entire maintenance environment and to provide a framework for management of the maintenance process and its associated functions. In the United Kingdom, the terotechnology model was developed (Kelly, 1984), the United States of America favored the life-cycle cost (LCC) approach (Geraards, 1992) and in Holland, the EUT model was employed (Gardner, 1988). Models were employed because experimentation was usually not a feasible means of evaluating the performance of the maintenance function.

Maintenance models therefore appeared to be approximate and imperfect but, by continually evaluating the results obtained from various models, and comparing them against the required output, it was possible to run the models until they provided satisfactory service.

Recently, research was focused more on workforce allocation across many maintenance types including heavy maintenance and line maintenance (Cheung et al., 2005b; Alfares, 1999; Ho and Chan, 1994). These research initiatives have attempted to develop either a mathematical model, an expert system, or an online system for allocating workforce in various maintenance situations. The drawbacks of all of these models, systems, methods are (i) they all focus only on part of the overall maintenance problem, (ii) lack integration at the process level, and (iii) do not have a holistic process and associated methods for the overall planning and scheduling of aircraft maintenance.

Based on the nature of aircraft maintenance planning and scheduling problem, and problems associated with many interfaced systems as reported above, it is anticipated that many airlines face with a number of issues in planning and scheduling across many types of maintenance using various models, approaches, etc.

3.2 Current Practices and Problem areas in Aircraft Maintenance Planning and Scheduling

Current practices and problem areas, common in many airlines, were evidenced through a recent study (internal report on investigation of an airline in the region, as part of a previously completed research project), on broader areas of unplanned maintenance, spare parts inventory and component maintenance are:

- Only about 50% of the work and parts replacement required during heavy maintenance can be planned. The other 50% is due to unplanned maintenance which is identified in inspection during lay-up.
- Inventory levels and planned purchases are based upon the forecast of historic usage, rather than any forward projection of parts usage based upon the aircraft schedule for future lay-ups.
- The cost of spare parts in inventory represents a significant investment for many airlines. However, by reducing spare parts inventory by the currently available methods without integrated planning, significant shortages are bound to arise.
- Where shortages occur in spare parts that have been sold off, the cost of re-purchasing these same parts is most likely greater than the selling price that an airline received and re-purchasing can also cause delays, as well as inconvenience, in maintenance.
- The purchase of spare parts currently appears to be primarily for unplanned replacement of unserviceable spare parts discovered during a lay-up.
and inventory cost reduction is a primary goal.

- There appears to be insufficient detailed information about unserviceable spare parts in inventory that require servicing or repair and a method for scheduling these spare parts to meet the scheduling and logistics requirements of the individual aircraft due for lay-up.

It has been noted in the literature that, typically 50-60% of all repair work during maintenance of an aircraft is unplanned, i.e. activated by inspection results. Since unplanned maintenance is a significant percentage of total maintenance, managing unplanned maintenance is vital for effective and efficient outcomes across many types of maintenance. Further, unplanned maintenance can cause serious consequences in the execution of maintenance orders involving a large number of materials, operations and resources.

The uncertainty of maintenance requirements stems from the inherent reliability of the aircraft’s components. Reliability is critical in the airline industry where safety of aircraft is of paramount importance. In this case, preventive maintenance strategies are the only options for aircraft maintenance. There are two basic approaches in this category and they are:

(i) Plan and schedule maintenance to overhaul unreliable components prior to failure.
(ii) Monitor the condition of unreliable components and replace when failure is imminent.

For scheduled overhaul of a component to be feasible there must be a readily identifiable point of accelerated deterioration (increased probability of failure) and the overhaul procedure must restore the component to a known condition, preferably a state of zero deterioration. The alternative to scheduled maintenance is condition-based (or on-condition) maintenance, i.e. perform maintenance based on the outcome of scheduled inspection and testing tasks. Most aerospace maintenance facilities employ a rigorous schedule of inspections, which leads to repair, replacement, and overhaul of components as required.

Thus, condition-based maintenance is the most significant, both in volume and importance, out of the two maintenance approaches to tackling the problem of component reliability in the aircraft industry. The impact on the planning and scheduling process is likewise significant – scheduled maintenance is, by its very nature, easy to plan for, whereas condition-based maintenance introduces uncertainty to the process and makes planning and scheduling of maintenance difficult. When the percentage of condition-based maintenance is around 50% of total maintenance, spare-parts inventory management is a huge problem in aircraft maintenance due to two main reasons: extremely high-valued inventories and longer lead times for many components. This means that consequences of condition-based maintenance in aircraft maintenance are severe in financial terms. Further, when conditioned-based maintenance requires rescheduling of many planned tasks within a larger maintenance project, rescheduling of overall maintenance project has been a serious problem, according to the selected airline and can be a common problem for any airline due to the size of maintenance projects and use of many interfaced systems for planning of materials, operations and resources.

3.3 Problems and Issues in the Interfaced System Environment

In interfaced system environment, project management for aircraft lay-up is implemented through standalone project management systems such as Microsoft Project. Materials (spare parts) required for maintenance are usually planned at the start of the relevant project activity, using a standalone MRP system. Execution of maintenance orders, in particular scheduling of operations and allocations of resources are usually done by operations scheduling of PAC (Production Activity Control). Due to the deployment of three different techniques (systems) for planning and scheduling of materials, operations, activities and resources, it can take a day or two to check if all planning of operations and resources are synchronized and materials are available. At the completion of each task, it can also take one or two days to check if all the task cards and additional work cards have been completed.

Thus, main problem arising from interfaced systems could be the out of phase plans for operations, resources and materials. Thus, interfaced systems lack the capability of simultaneous planning of many involved. Further, no forward planning capabilities exist with current interfaced systems and as a result, any forward planning required after the start of maintenance order cycle is not possible, leading to all manual intervention throughout the remainder of the maintenance order cycle.

Furthermore, finite capacity loading (planning) of resources is not possible with interfaced systems since no capacity planning techniques are incorporated into those interfaced systems. As a result, even with the availability of materials, maintenance project can be delayed due to unavailability of resources required for those operations in maintenance orders as part of the overall project.
Thus, the aircraft maintenance planning and scheduling require a holistic process that supports simultaneous planning of many components, forward planning of operations and finite capacity loading of resources. The process should also be able to handle critical aspects such as:

- Material requirements are not known with certainty. This is due to the unpredictable nature of system failure and the presence of ‘on-condition’ maintenance tasks.
- The duration of maintenance work may vary. The final composition of the maintenance project to be performed depends on the outcome of inspections.
- Maintenance tasks may be interdependent. Tasks may form a logical sequence of maintenance actions. Also tasks may contend for the same resource.
- Multiple configurations of the same type of aircraft usually exist. Projects should be customisable for unique configurations.
- Maintenance typically involves some measure of disassembly as well as re-assembly.

Integrated systems such as ERP systems can usually handle most of those issues discussed above. Further, ERP systems are capable of delivering required functionalities for aircraft maintenance. The specific ERP solution for aircraft maintenance falls into industry solutions of ERP since aircraft maintenance is a very specific problem in the airline industry. In this research, the MRO solution is investigated with a view to identifying integration aspects as well as particular issues related to such an integrated system.

4. INDUSTRY SOLUTION FOR AIRCRAFT MAINTENANCE, REPAIR AND OVERHAUL (MRO)

Although generic ERP systems support enterprise-wide business functions including plant maintenance, very few system provides have extended generic maintenance functionality for aircraft maintenance planning and scheduling across the spectrum of maintenance types. When generic ERP systems are deployed for aircraft maintenance planning and scheduling, they require interfacing with other systems for additional functionality required for planning and scheduling of aircraft maintenance.

On the other hand, industry solutions have most of the required functionality but still involve interfacing of many application modules and tools within the integrated system environment. Further, as a result of inherited limitations of individual techniques, industry solutions may still require considerable manual effort/intervention on finite capacity scheduling of resources and forward planning of maintenance as part of maintenance order cycle within maintenance projects.

The selected MRO solution is comprehensive and can plan and schedule a broader spectrum of maintenance types, based on hierarchy of the maintenance management through various strategies, techniques. The MRO solution is divided into four main solution areas: heavy maintenance, line maintenance, engine maintenance and component maintenance. Each maintenance solution area consists of a series of planning, control and execution building blocks. Apart from these maintenance solution areas, there is also configuration management as part of the complete solution map, in order to maintain both actual and “as-maintained” configuration of the aircraft throughout the life cycle.

Among those maintenance types, heavy maintenance and line maintenance constitute a bulk of aircraft maintenance. The component maintenance is involved across all types of maintenance, with different levels of involvement, depending on the strategy and requirements in individual maintenance jobs/projects. The major difference between two major problem areas is that heavy maintenance is a project-based maintenance while line maintenance does not involve project planning as part of the planning. Thus, heavy maintenance employs, among other techniques, MRP, PAC and CPM/PERT techniques for planning, control and execution of its components (materials, resources, operations, etc.).

4.1 Integrated Solution for Heavy Maintenance

Aircraft heavy maintenance, sometimes referred to as base maintenance, is used mainly for overhaul of aircraft structures. During heavy maintenance, aircraft is out of service and the aircraft’s time at the hanger is treated as the downtime. It also takes out of the revenue schedule for the whole duration of the maintenance. Other characteristics of the heavy maintenance are:

- Predominately heavy scheduled maintenance, but also modification accomplishment, aircraft alterations, corrosion control, structural repairs, etc.,
- Performance measures are turnaround time, cost efficiency, productivity,
- Component maintenance is directly related to heavy maintenance,
- Repair/overhaul of repairable components and rotables are handled by separate component workshops,
- Repaired components go back to aircraft/engine (closed loop) or are put into stock (open loop).
The heavy maintenance planning and scheduling of the industry solution (MRO) is built on a number of building blocks from Sales and Marketing through Spares Management. These building blocks are supported by underpinning processes and take appropriate routes of business processes at the time of planning, control and execution of each maintenance project. Heavy maintenance, in general, constitutes a project due to the nature of work involved, spanning over a considerable period of time with many components. Further, each building block of the solution incorporates a number of activities including:

- Service contract handling
- Maintenance planning
- Maintenance project management
- Production planning
- Maintenance execution
- Billing

These activities are carried out at different levels and times, using many techniques mentioned earlier, such as MRP, PAC and CPM/PERT. However, all of these individual techniques do have inherent problems, and can be part of integrated systems as well.

5. PROBLEMS AND ISSUES IN THE INTEGRATED SYSTEM ENVIRONMENT

5.1 Overview

Problems and issues associated with an integrated system environment are identified, based on investigation of the MRO industry solution. The scope of the investigation is limited to planning and scheduling of heavy aircraft maintenance. Two main areas of investigation are (i) maintenance order cycle and (ii) maintenance order assignment into activity of the overall maintenance project of C-checks. The maintenance order cycle, as part of overall aircraft heavy maintenance planning and scheduling, involves order creation with different task lists consisting of many operations and work centres. Maintenance order scheduling involves scheduling of operations and work centres. Planning of operations requires scheduling of work centres with finite capacity planning. Thus, problems associated with the maintenance order cycle can be divided into two areas: maintenance order scheduling (scheduled dates) and finite loading of work centres (resources).

In order to identify specific problems and issues within the industry solution, few business scenarios and associated testing plan were selected. The main objectives of the testing plan for identifying problem areas are to:

- Carry out planning and scheduling of maintenance orders, in order to test capabilities of simultaneous planning of all involved, finite capacity planning of resources and scheduling of maintenance orders over network activity with fixed duration.
- Report potential problem areas within planning and scheduling of maintenance orders with varying capacity loads, activity durations and order basic dates, in terms of capacity overloading and scheduled dates overlapping.
- Report functional deficiencies in planning and scheduling of maintenance orders and project networks, in terms of lack of warnings, possible missing links between data and applications.
- Monitor capacity loads on selected work centres over a period of time, in order to test automatic forward scheduling capabilities of the industry solution.

5.2 Numerical Example of Heavy Aircraft Maintenance Planning and Scheduling

Numerical testing of planning and scheduling of heavy aircraft maintenance was carried out in two stages: (i) testing of maintenance order planning at the time of order creation, and (ii) testing of scheduling of those orders when assigned into a network activity within an overall maintenance project.

Those tests were based on a set of master data (two task lists with set of operations using two work centres, project network with predefined activities). Master data was defined for a combination of plant 3700 (Orlando) and business area 3500 (Aerospace & Defence) in the MRO solution and are shown in Table 1.

<table>
<thead>
<tr>
<th>Network</th>
<th>903365 Engine Service Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity</td>
<td>0060 Replace the Rotor</td>
</tr>
<tr>
<td>Task Lists</td>
<td>Group 64 – ZACR01 Hydraulic Pump Check List (5 operations on ZAD-3710 work centre)</td>
</tr>
<tr>
<td></td>
<td>Group 71 – ZACR01 Engine Check List (10 operations on ZAD-3720 work centre)</td>
</tr>
</tbody>
</table>

5.2.1 Basic Start Date Scheduling and Capacity Loading at the Time of Order Creation.

It was noted from maintenance order creation that the
basic start date of maintenance order is set by the system, at the time of order creation and is the same as the order creation date. Further, the system sets scheduled start and finished dates, based on the duration of operations and are given as:

Scheduled Start (Date/Time) of the MO = Early Start of the first Operation of the task list.
Scheduled Finished (Date/Time) of the MO = Early Finished of the last Operation of the task list.

Table 2 shows scheduled start and finish dates/times for four orders created using two task lists of many operations with only one work centre. It was noted from maintenance order creation at different times that each order is assigned a different basic start date. Further, each order is scheduled with earliest start and finish times, independent of capacity availability of the work centre being assigned to each operation. The scheduled start and finish dates and times are shown in Table 2.

Table 2: Maintenance orders scheduled on ZAD-3720

<table>
<thead>
<tr>
<th>Order No.</th>
<th>Scheduled Start</th>
<th>Scheduled Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>813553</td>
<td>25/01/06 : 8.00AM</td>
<td>27/01/06 : 8.34AM</td>
</tr>
<tr>
<td>813554</td>
<td>26/01/06 : 8.00AM</td>
<td>30/01/06 : 8.34AM</td>
</tr>
<tr>
<td>813555</td>
<td>02/02/06 : 8.00AM</td>
<td>03/02/06 : 8.34AM</td>
</tr>
<tr>
<td>813556</td>
<td>27/01/06 : 8.00AM</td>
<td>27/01/06 : 5.00PM</td>
</tr>
</tbody>
</table>

Further, it was noted that the same work centre is loaded twice over the same period when two maintenance orders are created at the same time using the same task list. Since work centres are usually defined with only one unit of capacity, this would result in overloaded work centre over the operation period. This would result in continuous overloading of work centres due to limited capacities available at each work centre, when many maintenance orders are created at a given time. This requires manual intervention for resolving those capacity conflicts and sequencing of many jobs at each work centre. Thus, scheduling functionality in the system lacks finite capacity loading (scheduling) of work centres.

This suggests that scheduling functionality does not involve capacity availability check at the time of maintenance order creation, whether the work centre is already assigned with one operation, in the middle of one operation, or has no operation at the scheduled start time.

5.2.2 Scheduling of Maintenance Orders within a Network Activity

In order to test scheduling of maintenance orders (scheduled dates and capacity loads) within a network activity as part of a heavy maintenance project, three maintenance orders were created with variable start dates and durations. Those orders were created using different task lists (different work centres). Three combinations of variable maintenance order duration (MOD) and fixed activity duration (AD) considered are:

(i) MOD < AD
(ii) MOD = AD and
(iii) MOD > AD.

Those maintenance orders were then assigned to a selected network activity of the overall maintenance project. The activity, in this case, is an inspection activity with a specific start date, which is different to basic start dates of maintenance orders. This means that the network activity is fixed (both duration and dates). Since each maintenance order was created at different times, orders are originally scheduled to start earlier, the same time and later than scheduled start of the activity respectively. When the maintenance order is assigned into the activity, changes to maintenance order’s scheduled dates and times were recorded.

Irrespective of maintenance order’s start date falling outside or inside the network activity duration (i.e., before the start of the activity, during the activity or after the activity finish date), each maintenance order is scheduled to start at the network activity start date when they are assigned to the activity. Further, it was noted that the system assigns activity network finish date into the maintenance order finish date. For example, if the network activity starts on 21 February 2006, the new basic start date of the maintenance order is 21 February 2006. Irrespective of the maintenance order duration, the new basic finish date of the maintenance order is 23 February 2006 since activity finish date is 23 February 2006. This means that when a maintenance order is assigned to a network activity, maintenance orders are planned to start at the start of network activity. Further, maintenance order scheduled finish date is calculated, based on the maintenance order duration. This means that the order finish date and times are same as scheduled finish date and time of the last operation in the maintenance order.

This means that first two combinations of MOD and AD (i.e. maintenance order scheduled duration is less than or equal to the network activity duration), scheduled finished date/time of the maintenance order falls within the network activity duration. However, in the case of third combination (MOD is greater than AD), maintenance...
order’s scheduled finished date/time lies outside the network activity.

It was also noted that three orders created earlier are already overdue (originally scheduled in week 4 of 2006) as a result of no action (release) against them. As a result of three overdue orders and one current order, the work centre (ZAD-3720) is currently (week 5 – 30/01 to 03/02) overloaded as shown in Table 3. Although the system brings forward overdue orders, it does not provide (i) any warning on overloaded resources and (ii) finite scheduling of resources.

Table 3: Capacity Reqs. and load on ZAD-3720

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>5</td>
<td>71.00</td>
<td>48.00</td>
<td>148</td>
<td>-23.00</td>
</tr>
<tr>
<td>6 &amp; 7</td>
<td>0.00</td>
<td>80.00</td>
<td>0</td>
<td>80.00</td>
</tr>
<tr>
<td>8</td>
<td>0.00</td>
<td>64.00</td>
<td>0</td>
<td>64.00</td>
</tr>
<tr>
<td>9-13</td>
<td>0.00</td>
<td>80.00</td>
<td>0</td>
<td>80.00</td>
</tr>
<tr>
<td>Total</td>
<td>71.00</td>
<td>672.00</td>
<td>11</td>
<td>601.00</td>
</tr>
</tbody>
</table>

The capacity loading was further investigated using one of the work centres involved in maintenance orders created above. For example, the inspection activity in the maintenance project is scheduled for a period of 2 days, with total work of 20 hours. Since the activity is assigned to the work centre with the daily capacity of 160 hours, this work can be completed within one day period. However, it has been scheduled for a period of two days so that it can start at any time within the two-day time period. Actual work according to the operation in the maintenance order is only a fraction of available capacity (20 out of 320 hours).

Thus, the difference between scheduled finish and start times is equal to the duration, not the work required since the work is only a fraction of available capacity (20 units). This means that the activity can accommodate many maintenance orders over activity duration since the work centre does have 320 labor/machine hours of capacity during this two-day period. However, if no more maintenance orders are scheduled for the current time, the work centre is under-utilised.

Further, in the case of third combination (MOD>AD), the work centre is loaded only up to the scheduled finish date of the network activity rather than scheduled finish date of the maintenance order. This can lead to omission of capacity loads due to operations scheduled beyond scheduled finish date of the network activity.

In conclusion, the potential problems in the maintenance order assignment into the network activity are:
- Possible incompatibility between activity duration and maintenance order durations, in particular when MOD is greater than AD. (It is assumed that activity duration is set so that maintenance orders assigned should fit into the activity duration).
- Early start and finish dates of the network activity have remained unchanged after the order assignment and scheduling.
- No connection and/or link between activity duration/work and overall maintenance order duration.
- No finite capacity loading of resources as part of this order assignment.

Overall, planning and scheduling of maintenance orders at different times (creation, assignment into a network activity, scheduling), with no simultaneous planning, lead to incompatible planned dates and times. This also has lead to infinite capacity planning of resources (work centres) without any prior warning. Further, scheduling of many maintenance orders to the start of the network activity also looses the sequence of maintenance orders and may result in infeasible plans.

In summary, there is lack of simultaneous planning of operations and other components involved (materials, activity, work centres). Finite capacity loading of resources are not part of the solution and forward planning is not emphasized in the execution phase of maintenance order cycle.

5.3 Functional Issues in the Industry Solution

There are no warnings issued by the system when following situations are realized during the order creation and subsequent assignment into an activity.
- Loading of resources without availability check,
- Overloaded resources at the time of order creation,
- Discrepancy between scheduled finished dates of maintenance order and the network activity,
- Omission of some operations from the maintenance order at the time of order assignment,
- Activities of project network are not directly linked and/or integrated to maintenance orders, until they are assigned to one activity. Instead of structural tree, both network and maintenance orders are listed at the same level of the tree,
- There is no visibility of resource load over network
activities.

5.4 Limitations in the Planning and Scheduling Process

Overall, the industry solution provides integration of many planning and scheduling techniques at various levels. Since individual techniques do have their own inherent weaknesses, the integrated solution also suffers from following deficiencies.

- There is no simultaneous planning of materials and operations with finite capacity of resources,
- There is no sequencing of orders and/or operations within a heavy maintenance project activity,
- Earliest start scheduling of all maintenance orders leading to start all of them at the start of the network activity,
- There is no finite loading of resources. As a result, there is manual leveling of overloaded resources,
- There is omission of operations beyond the scheduled finish of the network activity at the time of order assignment to a network activity, when the activity duration is greater than the total duration of maintenance order.

6. IMPROVEMENTS ON PLANNING AND SCHEDULING PROCESSES

Since aircraft heavy maintenance uses many planning, control and execution techniques at different levels, integration of these techniques at planning levels would eliminate the need for separate planning of large number of components. Further, maintenance jobs are usually of the type project-based maintenance requiring not only planning of materials but also activities and resources. Currently, materials are planned using MRP while activities and resources are planned using project management techniques such as CPM or PERT. In order to streamline planning in project-based maintenance, maintenance projects are required to be representative of both structures (bills of materials and activity networks). Once these structures are integrated for project-based heavy maintenance, materials involved in the maintenance can be planned with finite capacity since the planning of materials would be based on the availability of resources. This is achieved through simultaneous planning of materials, resources, activities and other related components including suppliers of raw materials, using planning method based on combined MRP, PAC and CPM techniques with enhanced data structures.

Further, the planning and scheduling process can be improved by incorporating the full functionality of Capacity Requirements Planning (CRP) process including capacity evaluation, requirements and leveling. When CRP is integrated with MRP, PAC and CPM and is adopted with appropriate data structures, it would eliminate the need for capacity leveling at the time of execution. Also, the forward planning capabilities required for execution of maintenance orders can be enhanced using combined techniques of MRP, CPM and PAC. All these improvements are vital requirements for planning and scheduling of large maintenance projects, in particular for handling uncertainty in maintenance at the beginning of maintenance projects.

In summary, improvements are possible in a number of areas within the planning and scheduling of aircraft heavy maintenance projects. Those include:

- Simultaneous planning of materials, resources and operations,
- Finite capacity planning of resources (work centres),
- Sequencing and scheduling of operations and orders within project networks for feasible maintenance plans in terms of scheduled dates and the sequence,
- Capacity loading of all operations over the complete maintenance order duration rather than the activity network duration,
- Forward planning as part of the holistic process, not just as part of CPM at the beginning of maintenance projects.

Those possible improvements discussed above can be achieved though implementation of a holistic process for planning and scheduling, supported by appropriate data elements and structures. Those aspects are not discussed here since it is beyond the scope of this research paper.

7. POTENTIAL BENEFITS FROM PROCESS IMPROVEMENTS

Direct benefits and savings from proposed improvements on planning and scheduling process for heavy maintenance, can be realised in many areas. Those include:

- Reduction of inventories and effective planning of procurement of spare-parts. This means that probability of project completion on time and budget is increased.
- Finite capacity planning of resources can lead to cost reduction on overtime. This also means that completion times are more certain and thereby savings on time and budget. For example, overloaded work centres are usually accounted for 20-30% of the total work in the industry. Through better planning of these work centres can save
considerable overtime cost, reduce idle time of under-utilised work centres and improve turn-around times.

- Better planning of spare-parts requirements through simultaneous planning of materials and other components involved. For example, 80% of spare-parts can predicted with adequate forward planning.
- Better planning of spare-parts purchasing, based on forward planning and better use of unserviceable parts. (These parts will be primarily lower level parts purchased for use during the repair and service of larger assemblies, rather than the purchase of the larger assemblies.

Apart from benefits described above, the following benefits can be realised in other areas of maintenance within the MRO solution.

- Configuration improvement using integrated data structures,
- Forward planning of all components not only in heavy maintenance but also in line maintenance and component maintenance, using a new planning tool, combining traditional MRP, PAC, CPM and CRP techniques,
- Better data representation using unitary structures where functional location hierarchies integrate with task list hierarchies,
- Balanced forward planning based on disassembly and reassembly network,
- Reduction in aircraft heavy maintenance lay-up time using forward planning of all components involved in maintenance,
- Generation of new aircraft configurations after completion of each maintenance activity.

8. CONCLUSIONS AND FUTURE DIRECTIONS

The aircraft maintenance is a complex problem and requires an integrated approach for planning and scheduling of many components involved over a large spectrum of maintenance types. It was evidenced through current practices in many airlines that around 50% of total maintenance is unplanned, which is identified in inspection during lay-up. The paper identified that the MRO solution is comprehensive and robust in each area of maintenance types. The key improvement areas on the planning and scheduling processes within the integrated system environment are simultaneous planning of materials, operations and resources involved, forward planning of operations/tasks, and finite loading of resources. These improvements can be achieved by eliminating inherent problems of individual techniques associated with planning and scheduling. Potential benefits from the proposed improvements include on-time project completion, reduced inventory of spare-parts and reduced overtime costs. Implementation of proposed improvements in the current solution, through a new methodology for planning and scheduling, would form part of broader research project, currently being planned for collaboration with the selected ERP vendor.

REFERENCES


**AUTHOR BIOGRAPHIES**

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