Application of Maintenance Interval De-Escalation in Base Maintenance Planning Optimization

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Abstract

This paper presents a unique approach to aircraft maintenance optimization during base maintenance planning. The necessity to optimize maintenance follows from a need to reduce heavy maintenance visits that require significant downtime and are capital intensive. Further, unnecessary maintenance and frequent opening and closing of panels results in significant wear and tear, and thus reducing the inherent reliability of the aircraft. A simulation model has been developed to predict the maintenance requirement of aircraft in an airline operating under known conditions. Construction and validation of the model are based on knowledge and statistical data of actual operations and maintenance practices. The main use of the model is to group maintenance tasks into manageable packages that can be executed at extended maintenance intervals and within specified periods, and thus increasing aircraft availability. The concept of initial interval de-escalation of maintenance is introduced and its positive effects are demonstrated.

Keywords: Aircraft maintenance, clustering, simulation, optimization, Boeing 737NG

1. Introduction

With the increasing need to reduce maintenance costs and increase aircraft availability, the need to simplify the way maintenance is planned and executed has become a major issue in the aircraft industry. Aircraft manufacturers continue to develop aircraft with a low maintenance demand, while airlines strive to keep their maintenance costs as low as possible.

The Boeing 737 Next Generation (737 NG) is an example of such an aircraft, developed to demand less maintenance, as compared to previous versions of the Boeing 737 series. This 737 NG aircraft has a Maintenance Planning Data (MPD) document that is based on the Maintenance Steering Group (MSG)-3 philosophies. This is a task-based maintenance philosophy that looks at maintenance more at a task-level, as compared to previous philosophies, which were more focused on maintenance processes. The MPD is the document that airlines use to develop a customized maintenance planning. Many airlines that have this aircraft as part of their fleet tend to stick to the general method of developing maintenance plans that have been entrenched in the organization.

This paper is aimed at demonstrating a cost-effective maintenance planning and packaging concept that can lead to the reduction in direct maintenance costs, yet maintaining the reliability of the 737 NG fleet. Data used to develop the concept has been collected from an airline operating both scheduled (regular) and unscheduled (charter) flights within Europe.

2. Maintenance Planning and Scheduling

Maintenance engineers establish tasks and interval limits for various maintenance tasks; either based on the MPD (routine maintenance), Aircraft Modifications (AM), Repair Instructions (RI), Airworthiness Directives (AD) and Maintenance Instructions. Such maintenance tasks may be based on two maintenance activities:

1. Routine maintenance:

   This is performed in accordance with the instructions stated in the OMP. Such instructions and consequently utilization limits serve as a basis for the planning of aircraft maintenance.

2. Non-routine maintenance

   In cases of component failure, rectification may be performed immediately or may be deferred, depending on the severity. Operational critical items and safety related items (listed in Minimum Equipment List – MEL) would require immediate corrective action, while non-safety and non-critical items will be put on a Deferred Defect Sheet (DDS) for rectification when opportunity arises.

For maintenance planning purposes, Wang (2002) distinguishes between the long term strategic and maintenance concept, medium term planning, short term scheduling and finally control and performance indicators. Maintenance at the airline is broadly categorized into Line Maintenance (maintenance performed by the airline itself), and Base Maintenance (Maintenance work contracted out). Line maintenance is performed at short intervals (given in weeks). In reality, the realization of the planning for line maintenance deviates greatly from the intended planning. A reason for this may be attributed to the dependence of maintenance on the utilizations of the aircraft, unpredictable events, large work packages that are not executable within the stipulated time, and aircraft operations.

Base maintenance is performed every 1½-years (18 months). The airline has an operational pattern that is strongly seasonal (high between April –October, and low between November - March), as illustrated in Figure 1 below.
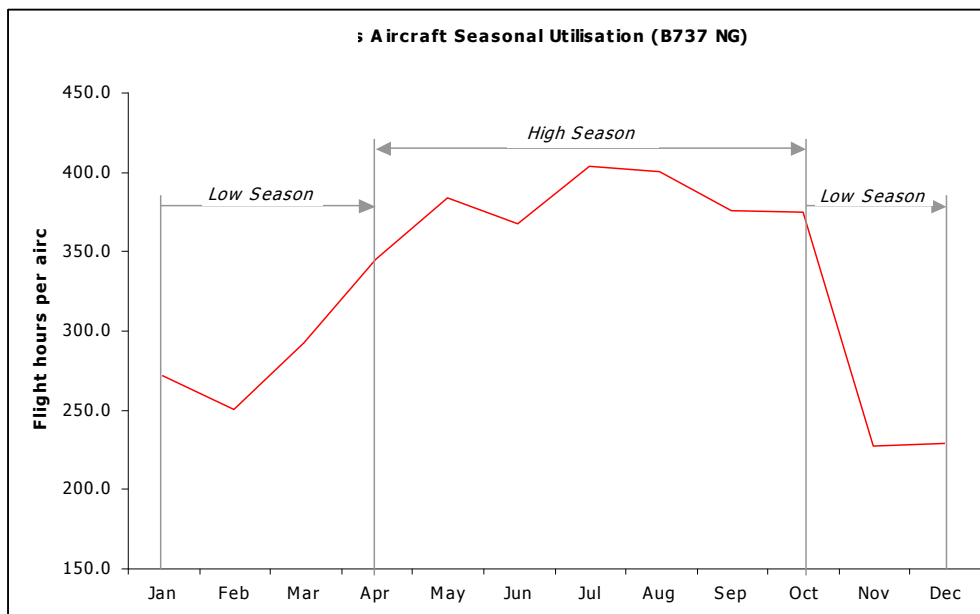

Figure 1: Aircraft seasonal demand

Base maintenance is preferably planned in the low season, because it requires aircraft to be withdrawn from operations for multiple days. However, a frequency of 18 months will always lead to maintenance due dates that fall in the high season. This problem is solved by performing the maintenance in advance (at 16 or 17 months), an undesired situation.

The effectiveness of the maintenance program and the aircraft maintenance characteristics are monitored through a Reliability Monitoring Program, maintained by the airline's engineering department. Performance indicators used to monitor the maintenance program and fleet performance include: the Technical Dispatch Reliability (TDR), Pilot Reports (PIREPS), Hold item Lists (HIL), Unscheduled Removals, No Fault Found (NFF) Reports, and

Confirmed Failures.

For each of these parameters, an alert level (an upper control limit) is set, at which action is necessary.

This paper focuses on the planning base maintenance for the airline. The models used will assume that base maintenance includes all work that requires a ground time of more than72 hours, and work for which the airline does not have certified personnel, hence requiring outsourcing.

3. The Simulation Model

In order to create maintenance task packages that will lead to the desired maintenance demand, a simulation model has been developed. This section describes the approach used in developing the model. Model verification and validation is also discussed.

3.1 Maintenance clusters definition and development

Clustering is the process of grouping maintenance tasks together into packages that can be planned in for execution. Clustering can be done by following two approaches, namely the Top-Down approach (answering the questions *When* maintenance and *What* maintenance), and the Bottom-Up approach (answering the questions *What* maintenance and *When* maintenance).

The <u>Bottom-Up</u> approach begins by evaluation what maintenance has to be done. By considering that the MPD document is a task-based maintenance document, each maintenance task is first analyzed so as to extract its properties, such as its interval, staff and tooling requirements and also man-hours required for execution. The main property considered per maintenance task is its maintenance interval. Maintenance intervals may have any of the following intervals: Limited by Days (D), limited by Flight hours (FH), limited by Flight Cycles (FC), limited by Days or Flight Hours – whichever comes first (D/FH), limited by   Days or Flight Cycles – whichever comes first (D/FC). Thereafter, all tasks requiring the same fixed conditions/procedure/cost, and the same maintenance interval limit, are grouped together to form Maintenance Task Packages (See also Wang, 2002). This applies to all maintenance tasks intended for line maintenance. All other tasks are grouped together based on their maintenance interval, and become Base Maintenance Checks.

The <u>Top-Down</u> approach begins by analyzing the aircraft utilization (in Flight Hours and Flight Cycles) requirement at an annual, weekly and daily level. The annual level reveals a seasonal pattern while the weekly and the daily levels do not reveal specific patterns.
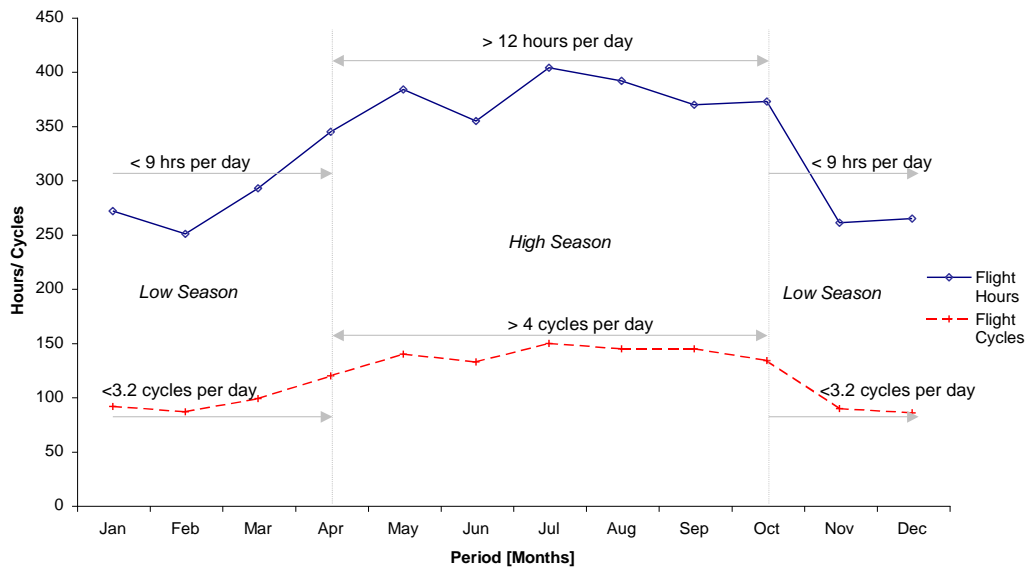
Figure 2: Annual Flight Hour/Flight Cycle output per aircraft

This conclusion on the weekly and daily utilization becomes more apparent when each of the weekdays is considered separately. The main reason behind this is that flight planners do not concentrate on the utilization per aircraft, but rather on the availability of aircraft at any given moment. Maintenance slot allocation follows these patterns; fixed slots are allocated at an annual level (for line and base maintenance). Ad-hoc slots can be located at a weekly and daily level (for base maintenance).

3.2 Cluster formation and evaluation

By combining the Bottom-Up and the Top-Down approach, Maintenance Task Packages and Maintenance Checks can be grouped together into maintenance clusters. Such clusters can either be static (base maintenance clusters) or dynamic (line maintenance clusters). Static clusters have a fixed content and are performed at predefined periods, while dynamic clusters may have a variable content and are performed frequently.

The clustering process is done using a computer model, developed in Visual Basic and MS Excel. Visual Basic software is used mainly because of simplicity in programming, and also due to the fact that data available within available from the organizations is presented in Excel format. The model developed is referred to as the *Maintenance Item Allocation Model* (*MIAM*). It is modeled to serve the following purposes: (1). Simulate the aircraft utilization (2). Calculate when a maintenance item turns due (3). Fit each maintenance item into a cluster (4) Generate maintenance clusters. It is hence a Hybrid Simulation model (Bratley, 1987, Hillston, 2001)

A Normal distribution is normally chosen for periodic distributions (Mattila, 2003). But owing to the fact that the seasonal pattern has to be incorporated into the model, the Monte-Carlo simulation method is used. A uniformly distributed range is specified, and from this, a random number is drawn. To cater for variations in utilization that might differ significantly from the current utilization, ten utilization scenarios are considered. These scenarios are based on three assumptions, as described by Bratley (1987). The assumptions are of (1) A conservative utilization: minimum conceivable daily utilization, (2) Most-likely utilization: utilization that resembles current pattern in airline, and (3) Optimistic utilization: maximum conceivable utilization. The ratio FH/FC is also varied to cater for changes within each scenario. Below is an example of the resulting utilization scenarios.

Table 1 Variable utilization scenarios

Utilisation:	Scenarios	Flight Hours	Flight Hours/Cycles
Conservative	Scenario 1	7 – 9 hrs/day	1.9 – 2.1
	Scenario 2	7 – 9 hrs/day	2.2 – 2.7
	Scenario 3	7 – 9 hrs/day	2.8 – 3.1
Most Likely	Scenario 4	9 – 11 hrs/day	1.9 – 2.1
	Scenario 5	9 – 11 hrs/day	2.2 – 2.7
	Scenario 6	9 – 11 hrs/day	2.8 – 3.1
Optimistic	Scenario 7	11 – 13 hrs/day	1.9 – 2.1
	Scenario 8	11 – 13 hrs/day	2.2 – 2.7
	Scenario 9	11 – 13 hrs/day	2.8 – 3.1
	Scenario 10:	*(Actual Utilisation)*	*(Actual Utilisation)*

MIAM combines maintenance item intervals with simulated aircraft utilization scenarios (high, average and low utilization) and maintenance scenarios (such as low maintenance frequencies). From these, the Maintenance Demand (in number of visits and maintenance man-hours) is calculated (Smit, 1994). Further, the model also calculates losses following from maintenance performed before the interval limits are reached.

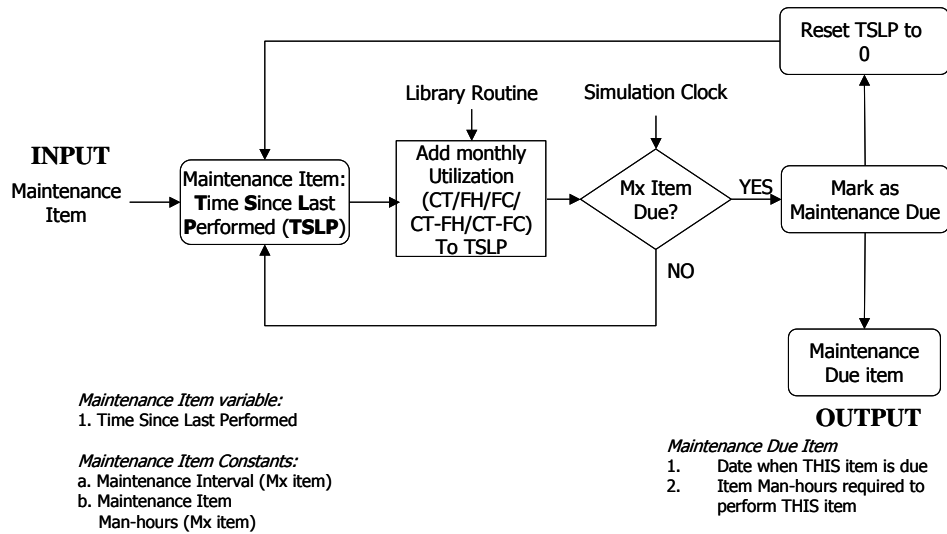The routine for calculating when a maintenance item is due is illustrated in Figure 3:
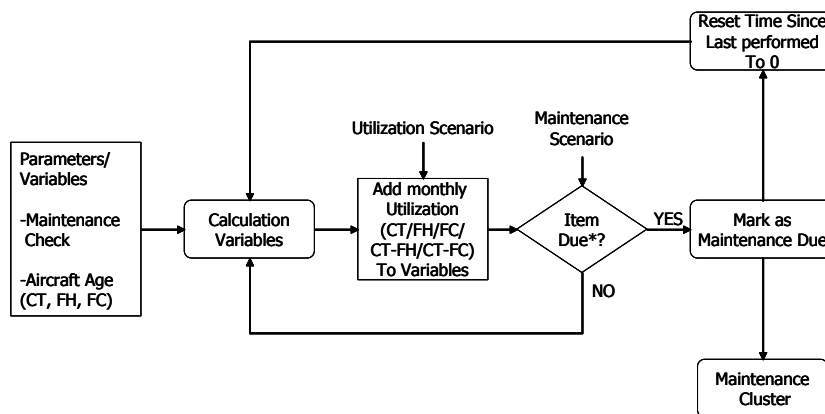
Figure 3 MIAM: Top model

Maintenance scenarios serve as the simulation clocks. The simulation increment may either be in months or weeks, depending on type of maintenance being considered (Line of Base).

The determination of maintenance checks to execute per base maintenance visit is much easier, mainly due to the large limits of the base maintenance checks.

* Due now or before the next maintenance interval

Clustering Process

Figure 4: MIAM Base maintenance

Unless otherwise stated, the following initial conditions apply

Table 2 Initial Conditions

Initialization Routine	
System Variables	0 CT, 0 FH, 0 FC
	A single aircraft is considered
Event Routine	0
Library Routine	(As stated)

3.3 Maintenance item interval de-escalation

De-escalation can be interpreted as a loss, in that maintenance items end up being performed more frequently than they ought to be performed. The loss will therefore be expressed in terms of labour, increased downtime and repeated set-up activities. The last two losses cannot be calculated directly. However, this paper will work further with the assumption that labour losses are representative enough for de-escalation losses.

Maintenance item clustering normally results in the de-escalation of maintenance item intervals. These are the maintenance intervals allocated to individual tasks by the engineering department (as indicated on the OMP). De-escalation can be given as a fraction of the interval that is not utilized, i.e.

$$de - escalation = \frac{ALV_i - lastp}{ALV_i} \; ; \; lastp \leq ALV_i \qquad (1)$$

Where: ALV_i = Airline interval (in CT, FH, FC)
                  $lastp$ = Time since last performed (accumulated utilization)

Hence, de-escalation in man-hours may be calculated as follow:

For Base Maintenance:

$$de - escalation = \frac{ALV_i - lastp}{ALV_i} \times BaseMhrs \qquad (2)$$

Where: $BaseMhrs$ = Base Maintenance man-hours (Boeing Man-hours x 3.6)

The pre-multiplication factor (3.6) is derived from work-floor experience on how Boeing

man-hours compare with the airline personnel performance, observed over a long period of time.

In terms of the exact cost of manhours, the following values are applicable:

Table 3 Maintenance Man-hour rates *(Source: Airline Project Management office)*

	Hangar	Cost per Manhour (in €)
Line Maintenance	Airline	31.76*
Base Maintenance	MRO	52.07*

3.4 Model verification and validation

3.4.1 Validation: Actual Process vs. The MIAM

Model Validation is done in order to ascertain that the model is a reasonable representation of the real life process: that it reproduces system behavior with enough fidelity to satisfy analysis objectives [Hillston, 2001].

a). Assumptions made:

- The aircraft considered makes flights on a daily basis, throughout the entire period considered.

- The aircraft performs flights solely for the airline, hence sticking to the airline's seasonal utilization pattern

- Maintenance clusters are performed as scheduled. No escalations and extensions are considered

b). Inputs and Distributions:

- Maintenance dates (Due dates, Time Since Last Performed) have a MM/YY format. Maintenance is always performed at intervals larger than 28 days(4 weeks)

c). Outputs: Maintenance man-hour demand is also regarded as downtime. The process concentrates more on man-hour demand variations, and downtime is expected to decrease if the maintenance frequency decreases.

3.4.2 Verification: MIAM Design and MIAM Realisation

Verification is intended to ensure that the model does what is intended to do (often referred to as debugging)

a)   The model calculates all possible inputs; with the exclusion of line maintenance frequencies lower than 4 weeks. If certain boundary conditions are violated (e.g.

escalation of maintenance interval limits), the model returns erroneous outputs (N/A, #VALUE etc.). This ensures that no invalid results are evaluated further.

b)   The modeled scenarios produce the desired utilization patterns.

c)   Base Maintenance does not vary greatly with changes in the maintenance utilization. Minimal changes are observed within each utilization scenario groups (conservative, most likely or optimistic). Sampling one scenario from each group may be considered to be representative enough for the other two.

d)   Line maintenance shows significant variations within the various utilization scenarios. Considering that the maintenance demand is calculated at short intervals, such variations cannot be ignored. Hence, all the 10 scenarios should be considered.

4. Results and Discussion

Base maintenance clusters are evaluated for an 18-month and a 24-month interval. Larger intervals would result in the escalation of maintenance interval limits. The results of the evaluation are tabulated on **Table 4** below.

Table 4 Base maintenance man-hour demand per aircraft: 10 yr period

Base Maintenance at an 18-Month Interval			Base Maintenance at a 24-Month Interval		
Base Mx Visit	Base Man-hours	De-escalation (Mhrs)	Base Mx Visit	Base Man-hours	De-escalation (Mhrs)
BMV 1 [Sep-04]	211	17	BMV 1 [Mar-05]	107	22
BMV 2 [Mar-06]	236	20	BMV 2 [Mar-07]	199	53
BMV 3 [Sep-07]	303	25	BMV 3 [Mar-09]	119	26
BMV 4 [Mar-09]	244	21	BMV 4 [Mar-11]	515	142
BMV 5 [Sep-10]	303	18	BMV 5 [Mar-13]	348	98
BMV 6 [Mar-12]	557	49			
Total Base Mhrs	1854	150	Total Base Mhrs	1288	341

It follows from Table 4 that base man-hour demand decreases significantly when the maintenance interval is raised to 24 months. The de-escalation does, however, increase. This can be assumed to be an expected conclusion, considering that the number of base maintenance visits in the same period is less by one.

However, further analysis of the results reveals that by performing the first base maintenance visit a few months before it is due (initial de-escalation), more gains can be made in reducing the base maintenance man-hour demand. The lowest man-hour demand follows from a 30-day initial de-escalation. This is shown on Figure 5 below.
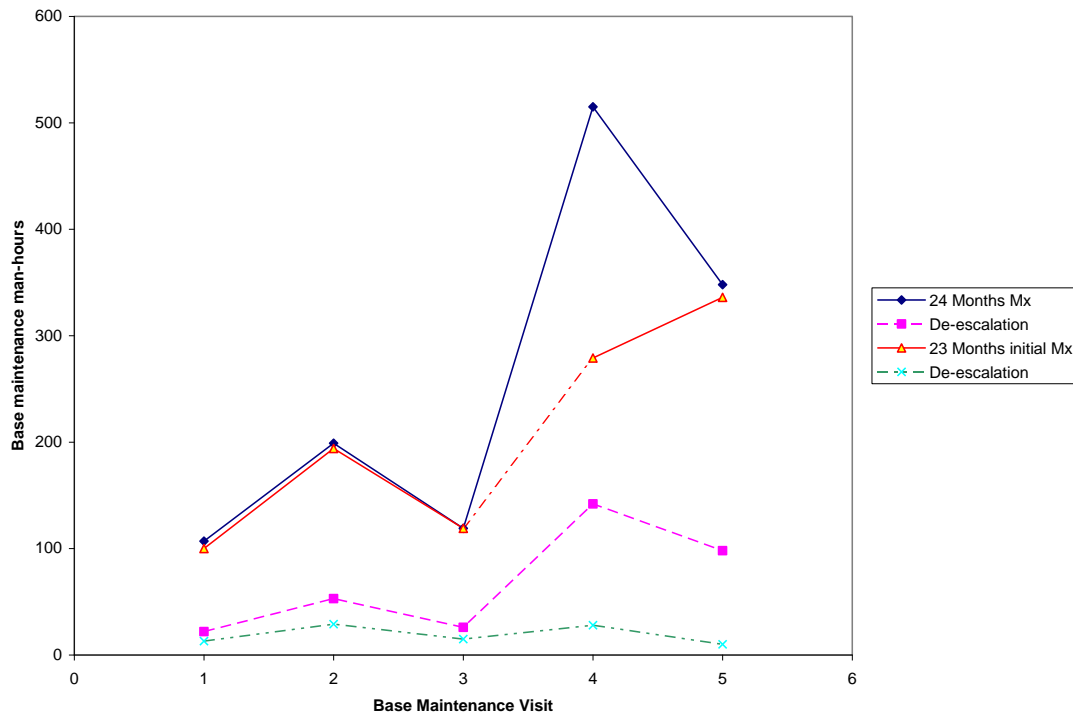
Figure 5 Base maintenance before/after initial de-escalation

Figure 6 below illustrates the effect of the initial de-escalation on the total Maintenance demand and on the total de-escalation (see also Table 5):
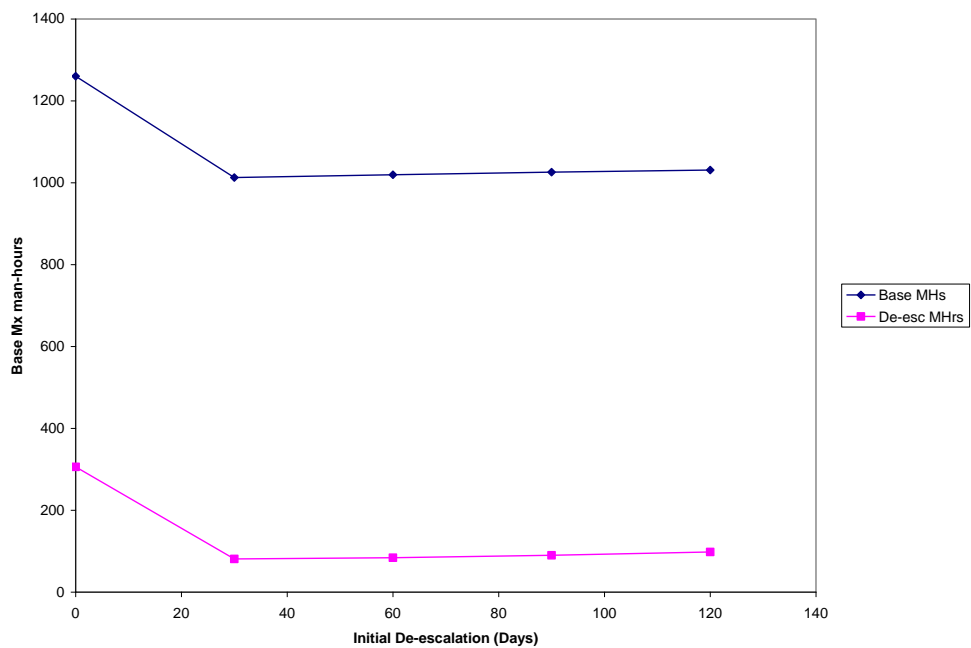

Figure 6 Effect of initial De-escalation on the maintenance demand/total de-escalation

It is evident that the total maintenance demand decreases by the application of an initial de-escalation. However, this decrease is only limited to about 30 days after which the initial de-escalation shows almost no effect to the total maintenance demand.

Table 5 Effect of initial de-escalation on various utilization scenarios

Initial De-esc	Base Maintenane	De-escalation	% De-escalastion
[Days]	Man hours	Man hours	.
0	1287	306	26
30*	**1020**	**81**	**9**
60	1032	84	9
90	1039	90	9
120	1039	98	10

On the other hand, the total de-escalation shows a sharper decline for an initial de-escalation of 30 days (*). By values above this, the total de-escalation increases gradually. The principle reduction (from 0-days), amounts to 26.9%.

Using the cost indication of man-hours given on Table 3, the reduction in the maintenance cost is determined as given on Table 6 below:

Table 6 Cost of base maintenance man-hours

Initial De-esc	Base Maintenance	Cost of base maintenance (in €)	
[Days]	Man hours	Airline	MRO
0	1287	40,875.12	67,014.09
30*	**1020**	**32,395.2**	**53,111.4**
60	1032	32,776.32	53,736.24
90	1039	32,998.64	54,100.73
120	1039	32,998.64	54,100.73

Base maintenance performed by the airline itself will always be cheaper than when the same is sourced out to a third party (MRO). However, the decision to perform base maintenance at the airline should be based on the availability of equipment, skilled manpower and space.

5. Conclusion

Based on the analysis above, it can be concluded that base maintenance can be performed optimally at a frequency of 24 Months. However, this optimum is achieved through the application of an initial de-escalation, which schedules the performance of the first base visit

at a date, not later than 23 Months after the introduction of the aircraft into the fleet. Using the existing maintenance tasks, a 30-day initial de-escalation leads to the least total de-escalation on the maintenance man-hours (7%), and consequently to the most optimum clusters for Base maintenance. The 7% translates to 95 man-hours, as compared to 341 man-hours (23%) before the initial de-escalation – a reduction of losses by **248** man-hours. This also translates to a reduction of **€ 13,902** in base maintenance cost. This reduction is for a single aircraft only. For an airline with a large fleet of Boeing 737-NG, this approach will, translate into huge savings for base maintenance activities.

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