Maintenance programme task intervals evolution on civil aircraft: a method based on in-service data

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Abstract

A scheduled maintenance programme should ensure airworthiness condition; support aircraft dispatch reliability performance and contribute to improve the aircraft availability performance. For some years, the airlines have been confronted with a very high competitive economic environment which leads them to be more cost-efficient in term of maintenance operations. One solution is then to consider the optimisation of the maintenance task interval.
Although some airlines perform this exercise on their own, the aircraft manufacturer is responsible when sufficient in-service experience can be collected for organising a maintenance programme evolution exercise. Evolution exercises are based on in-service data reported by airlines in the form of "nil findings/details of findings" for each maintenance programme task. However up to now, the evaluation of this data by the manufacturer and operators was mainly based on experience and "engineering judgment".
This paper describes a method and model that help to justify, homogenize this data assessment and to determine optimal maintenance task interval evolution.

Keywords: scheduled maintenance, task interval, in-service data, evolution exercise, reliability model.

1 Introduction

1.1 Context

A maintenance programme is a living document, which means it follows revisions and updates. Consequently, the aircraft manufacturer, airworthiness authorities and operators conduct a regular joint review to determine whether or not a new revision is needed. Proposed changes can be the result of:

1. A development of a maintenance programme for a new derivative aircraft;
2. An aircraft modification;
3. A change in regulation, analysis philosophy or interpretation of MSG-3 analyses;
4. In-service experience that causes an adaptation of an original task selection, or an interval selection.

This paper is mainly addressing the fourth point. It presents the "maintenance programme evolution" process which is launched when sufficient in-service experience is gathered.

1.2 Definition of relevant findings

In practice, a maintenance operator performs job cards derived from a maintenance programme task. Thus, findings reported by the operators have to be verified and especially if they exactly match to the completion of maintenance programme task findings.

In fact there are several types of findings:

- Findings related exactly to the completion of the maintenance programme tasks;
- Findings not linked to the maintenance task but found out during task accomplishment.

Only findings related to the maintenance programme task are assessed. They are called: relevant findings.

1.3 Nomenclature

- α = statistical risk
- λ = failure rate
- N = number of relevant findings
- NT = total number of reported tasks
- ρ = percentage of relevant findings
- SL = lower serviceability
- SU = upper serviceability
- I = task interval

1.4 Gathering data - sampling

By definition, there are less reported tasks than performed tasks. Reported tasks represent a sample of observation on which the decision is taken. The objective of this paper is mainly to support the decision-making from a sample of observation.

Thus, the percentage of relevant findings ρ is defined by:

$$\rho = \frac{N}{NT} \tag{1}$$

2 Method and model developed

Different types of methodologies (mathematical model, analogical approach), according to information available, have been investigated.

The common reasoning of these methodologies is to be conducted in two steps:

1. Analysis of the size of in-service data sample in three categories:
    - Data considered statistically irrelevant;
    - Data are considered moderately representative of the whole fleet. In this case, "engineering judgment" is necessary to confirm the trend and make the final decision;
    - Data are considered representative of the fleet and a decision can be made.
2. Then, if data are considered representative, proposal for interval evolution: increase, decrease or keep as it is.

The principle of the model, presented in this paper, is as follow:

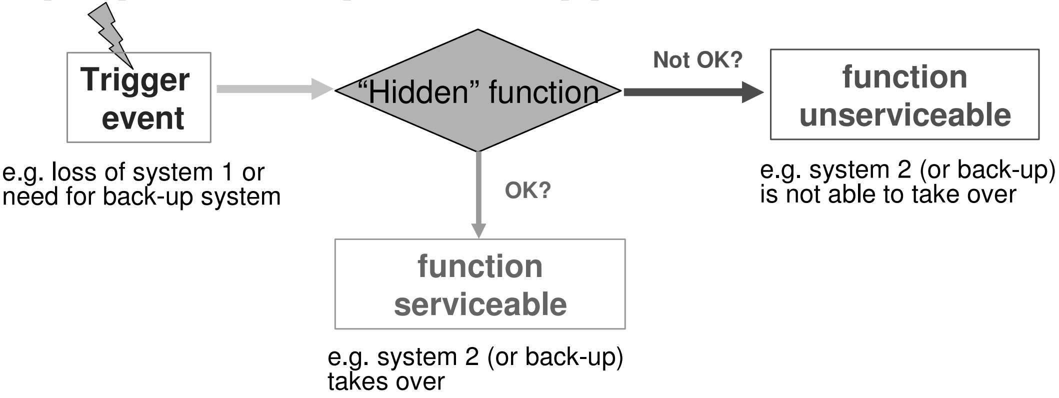


Figure 1. Model principle

Thus some quantitative parameters are needed to compare the efficiency of maintenance task interval. They will help to place the data on one or several graduated scales, in order to take a decision.
The model estimates serviceability (S) of hidden function, it means the probability that the hidden function is serviceable when a trigger event occurs.
The parameter taken to define the position of decision categories is the **serviceability of the function**.

2.1 Model hypothesis

2.1.1 No ageing

All equipments have an inherent reliability, which results in a failure rate.
The main hypothesis settled for the model is the non-ageing behaviour of systems studied. Thus failure rate λ is constant (no ageing).

This hypothesis means that the equipment has the same performance on any aircraft of any age. It allows us to sum scheduled maintenance experience (in-service data) from different aircraft corresponding to a given maintenance task:

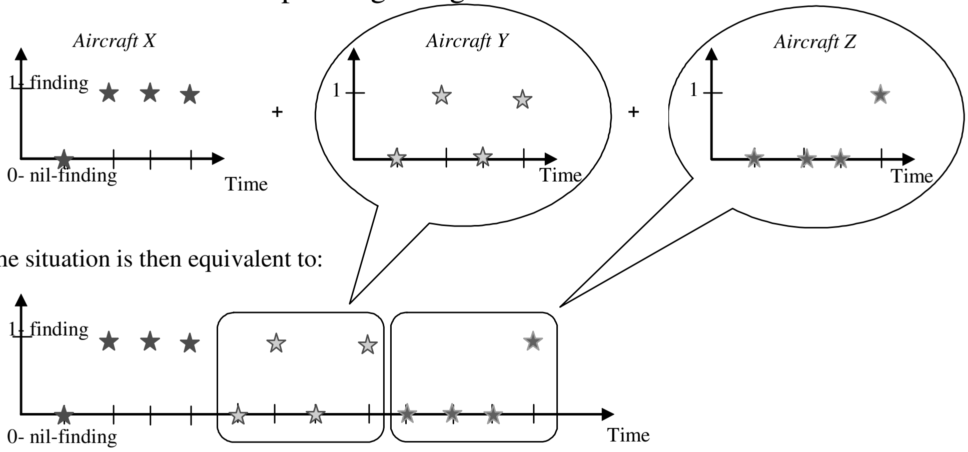


Figure 2. No ageing effect

In fact, we consider the experience of the fleet, instead of considering each aircraft independently. This hypothesis is often made in the study of avionic systems.

2.1.2 The order of magnitude of the initial interval is well chosen.

This hypothesis means that the initial interval has been selected (and is not too high) so as to avoid that failure of the hidden function becoming evident between two maintenance tasks and generating an event (e.g. aircraft turn-back, delay). Mathematically speaking and according to the model principle schematic, this hypothesis means that the time, the hidden function becomes unserviceable because a trigger event and between two maintenance tasks, is negligible.

2.2 Serviceability computation

Serviceability S(I) is the probability that the hidden function is serviceable when a trigger event occurs.

The probability of a failure on hidden function during an interval is:

$$p(I) = 1 - e^{-\lambda I} \tag{2}$$

Then serviceability S(I) is:

$$S(I) = \frac{-p(I)}{\ln(1 - p(I))} \tag{3}$$

The exact value of serviceability of the function S(I) is not directly computed. Indeed, this value is actually not known, because of the sample of observation. Thus, the confidence interval method has been used: a risk α is fixed, and the lower serviceability SL(I) and the upper serviceability SU(I) are computed.

Thus,

$$SL(I) \le S(I) \le SU(I) \tag{4}$$

The interval SL(I)-SU(I) is the confidence interval. The probability that the exact value of S, for the whole fleet, is bounded between SL(I) and SU(I), is (1-α) %.
By using ref. [1], [2], we demonstrate that:

$$SL(I) = \text{function}\ (\rho, NT, \alpha) = SL \quad (5)$$

$$SU(I) = \text{function}\ (\rho, NT, \alpha) = SU \quad (6)$$

Remarks:

- For ρ = 0, we have SU = 100%;
- For ρ = 100%, we have SL = 0%
- (SU – SL) gives the spread of uncertainty on serviceability. When NT tends to infinity then (SU – SL) tends to zero.

2.3 Choice of the risk α

By using the confidence interval method, a new parameter is introduced: risk α. Once chosen, α value is introduced in the model and shall not be modified.

For fixed values of ρ and NT, using (5) and (6), we have SU, SL as function α:

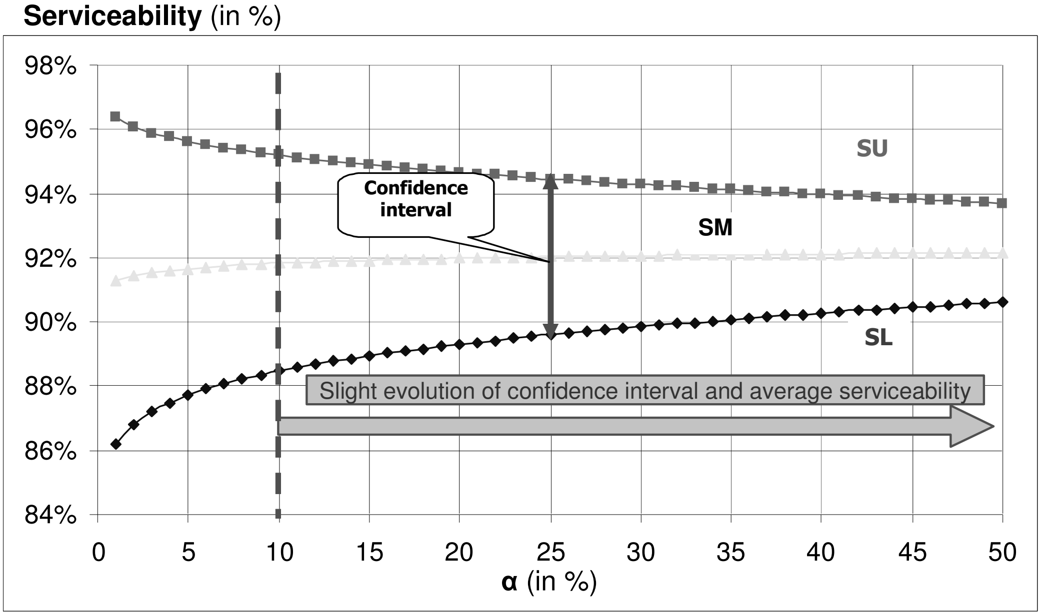


Figure 3. Variation of SL and SU as function of α
(for a given ρ and NT).

In this example, with α = 25%, there is a probability of 75% that the real serviceability of the function on the whole fleet is bounded between 89.5% and 94.5%. On this graph, the light grey curve is the arithmetic average of SL and SU.

How to choose α:

- On one hand, the risk should be low. Then, if the risk is low, the probability of having the real value within in the confidence interval is high;
- On the other hand, the confidence interval should be low to have a better view of the actual value to make a decision.

- However as shown on the previous graph, the smaller the risk, the bigger the confidence interval:
  - If the risk is 2%, the difference (SU-SL) is huge: the confidence interval is important, and the data may be irrelevant. Therefore it is difficult to make the right decision;
  - If (SU-SL) is too low, the risk is too high to make the decision with only the confidence interval.

For industrial application, a good compromise is to take $\alpha = 10\%$

2.4 Evolution guidance table and graph

SL and SU are also depending of ρ, NT and I. As the maintenance engineer has only access to data reported, a guidance [ρ;NT] table has been defined using (5) and (6):

Table I: Evolution guidance table for I given

ρ percentage of findings / ↓ NT: number of task reported →	**1**	**10**	**...**
0%	SU (ρ, NT, α) SL (ρ, NT, α)	SU (ρ, NT, α) SL (ρ, NT, α)	...
5%	SU (ρ, NT, α) SL (ρ, NT, α)	SU (ρ, NT, α) SL (ρ, NT, α)	...
...	...	...	...

These couples [SL;SU] can be visualised on 2D graph:

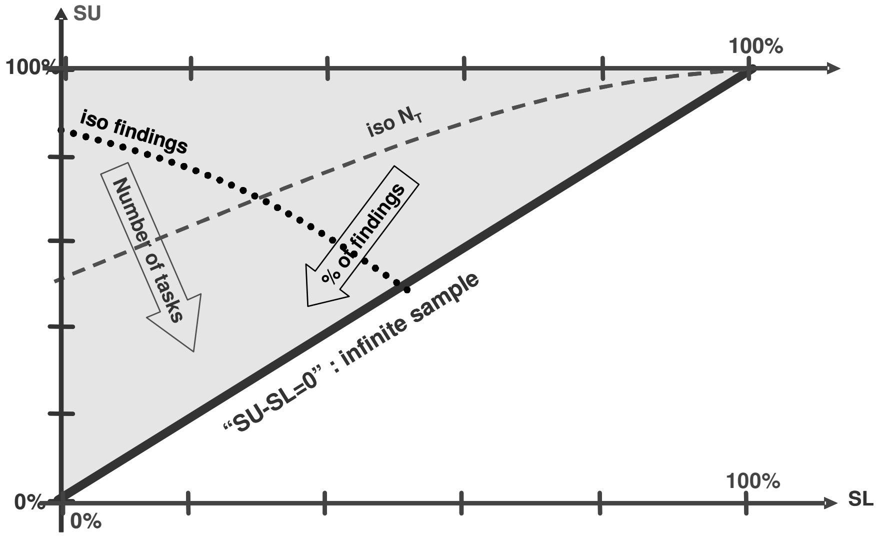


Figure 4. Decision graph SU/SL.

The grey zone represents all possible values of couples [SL;SU].

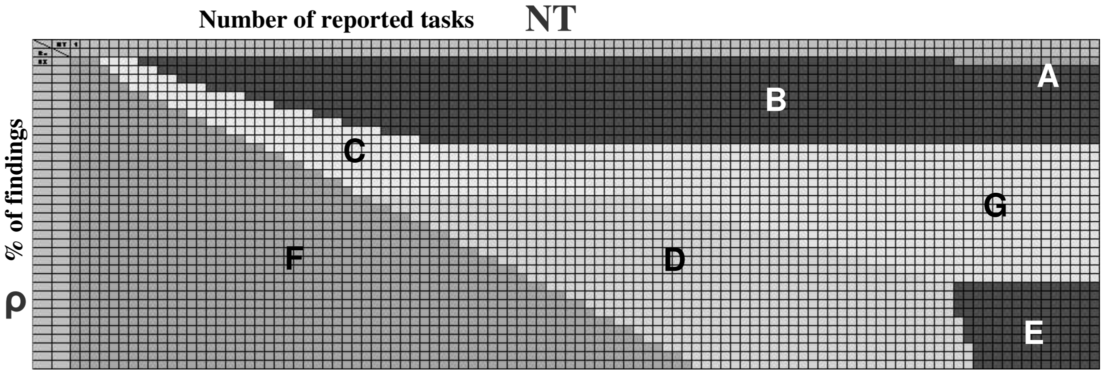
2.5 Decision categories

In order to help the maintenance engineer to decide on interval evolution, different decision categories (A, B, C, D, E, F, and G) have to be defined according to the example below:

- Low uncertainty and high serviceability (low percentage of findings): category A and B
- Low uncertainty and medium serviceability (medium percentage of findings): category G
- Low uncertainty and low serviceability (high percentage of findings): category E
- Medium uncertainty and medium serviceability (low percentage of findings): category C
- Medium uncertainty and low serviceability (high percentage of findings): category D
- High uncertainty: category F

The boundaries lines between decision categories have to be set by the aircraft manufacturer and operators taking into account their in-service experience and engineering judgment.
The result of applying theses decision categories to Table I is:

Table II: Evolution guidance table with decision categories.



Placing the number of tasks and the percentage of findings of the tasks under consideration on this table, the maintenance engineer is able to get an indication about the task interval adjustment.

2.6 Evolution of interval

To check if the boundary lines between categories A, B, G and E (most reliable data) have been well defined, it is necessary to see the influence of an interval evolution on the serviceability.
Let's suppose that a decision is made to increase the interval of a couple [ρ;NT] and [SL;SU]. From the new interval, we extrapolate (using ref.[1]) new couple [SL;SU] and by using Table II, we have new couple [ρ;NT].

Generally speaking, if every point from categories B, A and E falls down into category G after interval evolution, then the boundary lines have been well positioned. In other words, after interval evolution, any task should have statistically the best targeted performance $[\rho;NT]$.

3 Industrial application

Let's take an example of a smoke detector with its associated maintenance task interval of 500 Flight Hours (FH). The in-service data collected is: 217 tasks reported and 1 relevant finding.
Thus <u>model inputs</u> are:

- α = 10% risk on data;
- NT = 217 total number of task reported;
- N = 1 number of relevant findings;
- ρ = 0,5% percentage of relevant findings

<u>Model outputs</u>

- SU = 100% upper serviceability
- SL = 98,9% lower serviceability
- SU-SL = 1,1% confidence interval

By experience, the decision category for this example is "B" for "low uncertainty and high serviceability (low percentage of findings)". So from experience and from computation results (of the in-service data gathered), the maintenance task interval can be increased easily. It supports target values of the new interval framework.

4 Conclusion

This method gives guidance on how to consider processing a maintenance programme evolution exercise. It proposes the use of several categories for interval adjustment decision. It gives indication how to choose between these categories, using a $[\rho;NT]$ table.
The model provides an assessment of maintenance efficiency (serviceability) that can be used to define the shape of decision categories on the $[\rho;NT]$ table. The aircraft manufacturer and operators decisions still need to define the boundary lines, according to their in-service experience and engineering judgement.

Besides, it should be highlighted that the decision categories depend also on the targeted percentage of interval evolution.

From a practical side, the $[\rho;NT]$ table is easy to use for the maintenance engineer. Of course the maintenance engineer may override the result given by the $[\rho;NT]$ table. The evolution table remains as guidance for an evolution exercise.

5 Acknowledgements

The research presented in this paper is a part of VIVACE project result. The VIVACE (Value Improvement through a Virtual Aeronautical Collaborative Enterprise) integrated project is partly sponsored by the Sixth Framework Programme of the European Community (2002-2006) under priority 4 “Aeronautics and Space” as integrated project AIP3 CT-2003-502917. The work was performed at the EADS-Innovation Works in Suresnes, directed by Airbus Maintainability & Maintenance Engineering, with collaboration from the Université Paul Sabatier.

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