CONDITION-BASED OPERATIONAL RISK ASSESSMENT - AN INNOVATIVE APPROACH TO IMPROVE FLEET AND AIRCRAFT OPERABILITY: OPERATIONAL RISK

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OVERVIEW

This paper is part of the session "Condition-based operational risk assessment - an innovative approach to improve fleet and aircraft operability" presenting results of current research within the European FP6 research project TATEM[1]. This second part of the session is concerned with the condition-based operational risk assessment function. The function uses the results of the condition view explained in [1] and provides important input for the economic decision-support and operational planning function detailed in [2]. The operational risk function in this scope calculates a set of discrete probabilities of operational interruptions and their estimated costs for a given operational plan for an aircraft as one major input for operational support.

1. INTRODUCTION

The European aeronautics industry has identified the maintenance domain as an important area for the improvement of operational performance and cost effectiveness. Today maintenance activities can amount to as much as 20% of an operator's direct operating costs, driven not only by scheduled maintenance but also by unscheduled maintenance events often leading to costly delays and cancellations [7]. The reduction of unscheduled maintenance events interfering with the operational planning of airline operators is therefore one major objective.

Today's research activities are focused on the implementation of IVHM[2] capabilities for future aircrafts and fleets. This approach will allow condition-based determination of current components and aircraft health as well as the prediction of future aircraft behaviour in terms of upcoming health degradation and resulting operational risks for given operational planning. Finally it will support the economic decision-making in the maintenance management domain.

1.1. Scope and problem description

The aircraft operability is an often used but complex parameter describing the operational performance of an aircraft. It can be decomposed into the operational reliability, the aircraft availability and the maintenance costs (see more details in [1]). All these parameters are used to reduce the number of unscheduled maintenance events leading to operational interruptions, non-availability for service during such events and additional unscheduled maintenance costs. Beside the technical performance of aircraft components and systems, the maintenance management in aircraft operations is also an important factor.

Influencing the aircraft availability and scheduled maintenance costs is a task more related to the strategic maintenance management dealing with optimisation of hangar maintenance on aircraft and fleet level. Especially the operational reliability is more driven by short-term planning of the aircraft operation and later-on managing the performance of operations without interruptions. Here the injection of additional information indicating operational risks for operational planning alternatives shall improve decision-making. For such risk assessment, the current condition of relevant aircraft components and their future behaviour in terms of upcoming maintenance needs have to be identified as well as additional costs and dispatch delays due to unscheduled maintenance events.

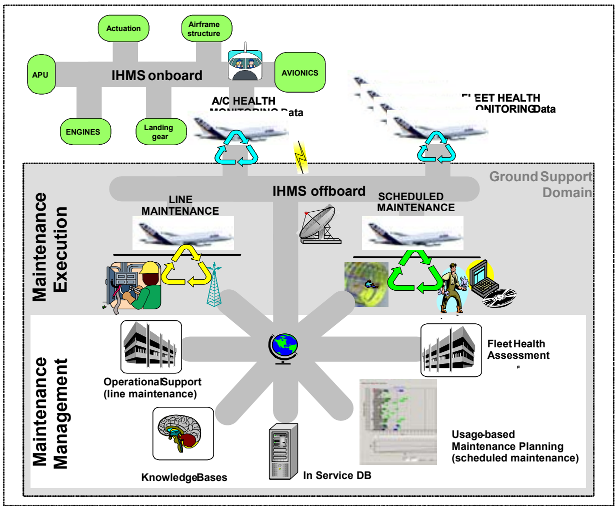


FIG 1. IHMS[3] overall architecture and maintenance management as part of the ground support [8]

The approach discussed in this paper focuses on the short-term operational support as a task of the maintenance management domain (see FIG 1). The operational support use case addresses the economic

[1] TATEM: Technologies and Techniques for New Maintenance Concepts, EC contract AIP3-CT-2004-502909
[2] IVHM: Integrated Vehicle Health Management
[3] IHMS: Integrated Health Management System

decision support for aircraft operational planning by maintenance management.

1.2. Architecture and functional model

The operational risk assessment function is part of the decision support layer of the chosen OSA-CBM[4] architecture. The OSA-CBM architecture provides a communications framework to monitor the operation and health assessment of complex systems and the prediction of remaining useful life (RUL) of the system or subcomponents for further decision-support of the operation [6].

As shown later in this paper the input for operational risk assessment, the current condition and remaining useful life (RUL) of aircraft systems and subcomponents are provided from prognostic and health assessment layers using the condition view function (see [1]). While the health assessment and RUL prediction are dedicated to specific systems and subcomponents the decision support layer has to integrate all to the aircraft level for operational support. That also includes the incorporation of external legacy data sources not available on the aircraft system or subcomponent level, e.g. operational plans, maintenance resource availability, etc.

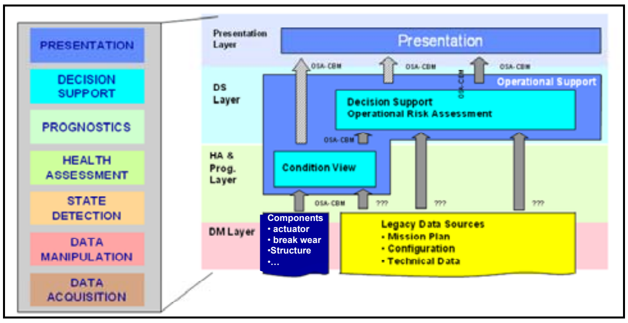


FIG 2. Operational risk assessment within OSA-CBM architecture and operational support module

FIG 2 shows the OSA-CBM stack and the location of decision-support including the operational risk assessment as a sub-function of the operational support use case.

The functional model for the operational support use case (see FIG 3) is compiled by three major functional blocks, the condition view, the operational risk assessment and the decision support. In addition, it has support functions for results presentation (user interface) and external data supply (legacy data bases).

The condition view functional block (green, part of health assessment and prognostics layer) depicts the current health condition and predicts the remaining useful life for the monitored aircraft components. For these calculations the function incorporates existing component health status information and RUL prognostics coming from lower OSA-CBM layers and legacy data such as future operational planning, history data, etc. and provides RUL information with improved accuracy with respect to expected future utilisation as output. In addition the failure models for each managed component have to be provided to the operational risk assessment function.

The operational risk assessment functional block (light blue, part of the decision support layer) calculates the operational risk in terms of expected probability for unscheduled disruptions of the given operational plan and resulting additional costs.

The decision support functional block generates operational plan alternatives for aircraft operation and calculates performance parameters for the multi-criteria decision support selection of the most promising operational plan alternative. The operational risk assessment result is one major input for this multi-criteria decision support.

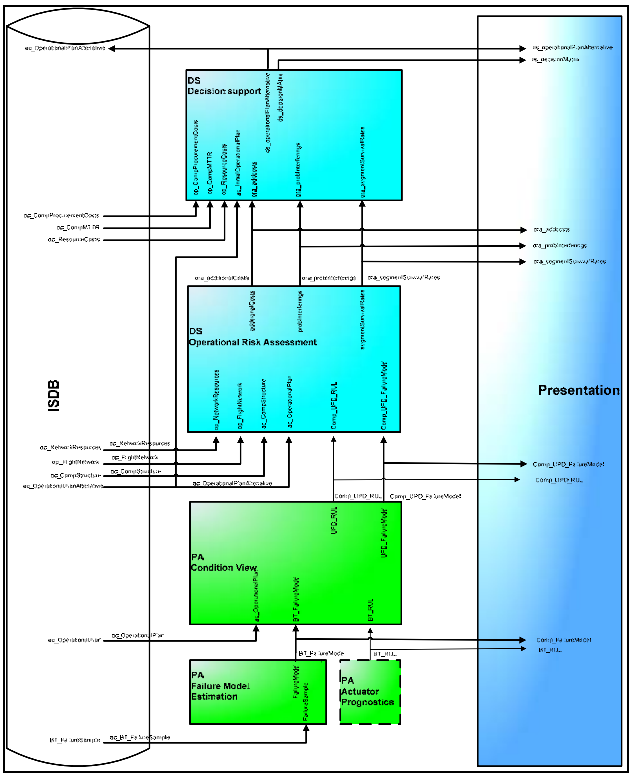


FIG 3. Functional model of operational support use case

All functional blocks provide output usable for maintenance management staff which is presented through the presentation function (deep blue). The legacy data supply is represented by the ISDB[5] (gray block).

The condition view and decision support functional blocks are discussed in detail in [1] and [2]. Further work therefore focuses on the operational risk assessment functional block.

2. OPERATIONAL RISK ASSESSMENT

The operational risk assessment in the scope of aircraft operational support calculates a set of discrete probabilities of operational interruptions and their estimated costs for a given operational plan for an aircraft as input for economic decision-support.

[4] OSA-CBM: Open System Architecture for Condition-Based Maintenance, see [6]

[5] ISDB: In-Service Database

2.1. Concept

In the guidelines of Basel II "operational risk is defined as the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events. This definition includes legal risk, but excludes strategic and reputational risk."[6] This term is mostly used in banking. In the context of this paper the operational risk is seen as the risk of an unscheduled maintenance occurrence during the operation of an aircraft. Such incidences disrupt the itinerary of the aircraft.

The operational risk assessment in this context describes the calculation of probabilities of operational interruptions caused by unscheduled maintenance events and the estimation of costs caused by them (based on specific cost functions of the point of occurrence - these points being the bases within the flight network where operational schedules can be interrupted).

Root causes of operational interruptions are non-deferrable maintenance actions which prevent the aircraft dispatch in time. An aircraft loses its dispatch ability, if mandatory components listed in the MEL[7] are out of specified function. The fundamental concept therefore is the modelling of the aircraft as a set of "managed" components with individual failure (behaviour) models and structural interdependencies representing the MEL constraints for aircraft dispatch ability. The failure of one component does not mandatorily cause an operational disruption, if redundancy is implemented.

The process of operational risk assessment starts with the estimation of the "survival rate" for each "managed" component as well as the complete aircraft for an operational plan. The operational plan is defined as a sequence of flight segments, the itinerary. The "survival rate" for each flight segment indicates the probability of operational disruption.

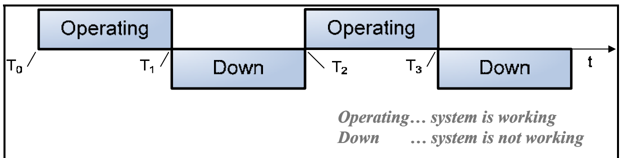
The capabilities of each base along the itinerary can be different with respect to repair resources (e.g. availability of spares and maintenance personal), repair time and costs. So the risk of delays or cancellations and costs will vary. The second step of operational risk assessment is the calculation of the probability for delays or cancellations and of related costs for each base along the itinerary.

2.2. Calculation of survival rates

The estimation of "managed" components and aircraft level "survival rate" uses an implementation of the Maintenance Free Operating Period (MFOP) approach. It allows the reliability assessment of complex technical systems. The primary goal is the calculation of the survival probability for a discrete time period with regard to a given level of risk for the availability of the technical system [9].

The parameter to be calculated in this assessment is the ***MFOPS*** (Maintenance Free Operating Period Survivability), the probability of survival during a time of t_{mf} time units. t_{mf} is, in this context, the concrete MFOP cycle and defines the lapse of time the system will be able to perform its function accordingly.

The ***MFOPS*** for a component characterised by alternation of "operating" and "down" and 0.95 survivability is defined in FIG 4.



$$MFOPS(t_{mf}) = P[(T_{2i+1} - T_{2i}) \geq t_{mf}] \geq 0,95$$

with WEIBULL distributed lifetime:

$$MFOPS(t_{mf}) = exp\left(- \frac{(t + t_{mf}^{\beta}) - t^{\beta}}{\eta^{\beta}} \right)$$

FIG 4. MFOPS definition [9]

In addition, the MFOP approach considers the structural interdependencies of complex systems. Components without redundancy are represented as a serial structure; redundant components are represented as parallel structure. The ***MFOPS*** for a series of ***i*** cycles and ***n*** components (serial structure) with specific probabilities of surviving ***R*** which be defined as:

$$MFOPS(t_{mf}, i) = \prod_{k=1}^{n} \frac{R_k(i \cdot t_{mf})}{R_k([i-1] \cdot t_{mf})}$$ [9]

Taking this theoretical model into account, the estimation of aircraft "survival rate" can be performed based on the description of "managed" component interdependencies as defined in MEL and the component-specific WEIBULL lifetime distribution.

FIG 5 shows the implementation of the MFOP approach done in cooperation with the Technical University Dresden.

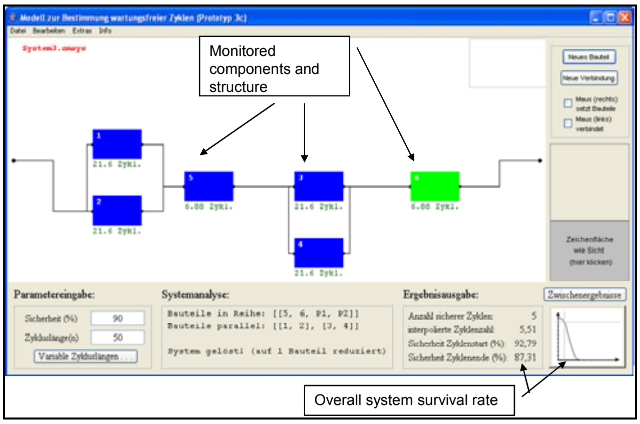


FIG 5. MFOP modelling implementation sample [4]

The implementation allows the modelling of an aircraft as a set of "managed" components. The components are described by individual failure models (WEIBULL lifetime

[6] See Basel II (§644 of *International Convergence of Capital Measurement and Capital Standards)* at http://www.bis.org/publ/bcbs128.pdf

[7] MEL: Minimum Equipment List

distributions) and their interdependencies using a graphical structure. The itinerary is modelled as a series of cycles (with variable cycle length). Finally the MFOP implementation calculates the ***MFOPS*** parameter for each single component as well as the overall system (aircraft) for each cycle.

2.3. Assessment of operational risk

The second step of operational risk assessment deals with the calculation of the probability of possible occurrences as well as their according costs[8].

In this context, four types of occurrences are defined for an operational plan to be assessed:

- Continue without incidence
- Failure A: Repair within block time
- Failure B: Repair within tolerable delay time
- Failure C: Abort operational schedule

The capabilities of bases visited along the itinerary are described by:

- Spare part availability:
  - Part locally available [%]
  - Part can be flown in for repair within block time [%]
  - Part can be flown in for repair within tolerable delay time [%]
  - Carrier capacity available for repair within block time [%]
  - MRO capacity available for repair within block time [%]
  - Carrier capacity available for repair within tolerable delay time [%]
  - MRO capacity available for repair within tolerable delay time [%]
  - In case of cancellation: Rebooking possible [%]

- Immediate repair ability:
  - Immediate repair within (base-dependent) block time with individual capacity of carrier
  - The same with MRO capacity
  - Repair within (base-dependent) tolerable delay with individual capacity
  - The same with MRO capacity

The expected costs are base-specific and the product of occurrence costs and probabilities. As cost elements for each base the following cost elements are considered:

- Flying in of spare part
- Exceeding block time (‚penalty')
- Internal repair Carrier
- External service MRO
- Rebooking (in case of cancellation)
- Substitute A/C (in case of cancellation)

Using these probabilistic parameters and the components and aircraft ***MFOPS*** along the itinerary, the calculation model (implementation as a Monte Carlo simulation) estimates the probability of occurrences and the related expected costs.

FIG 6 shows the results of calculating the operational risk for an itinerary with 10 flight segments. The upper left chart contains the survival rate / probability of failure for the "managed" component (or aircraft) on each outer base for the given itinerary. These parameters are provided from the MFOP model. The upper right chart describes the probability of delays or cancellations as a result of the defined base repair capabilities. Finally the expected costs and occurrences are shown in the bottom charts. In this example, an unscheduled event is expected at the end of the itinerary. Due to the low base capabilities the probability of a cancellation is high.

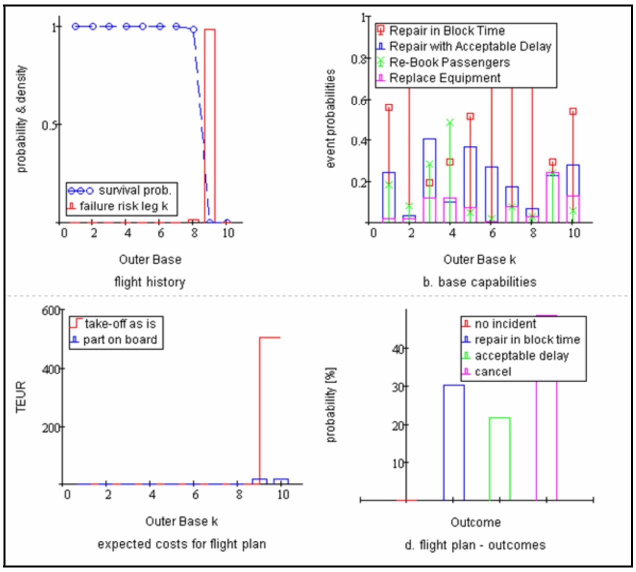


FIG 6. ORA calculation example [5]

3. IMPLEMENTATION

The described operational risk assessment functions have been implemented in a laboratory prototype for demonstration. The demonstration purposes are:

- Architecture and major functions for operational risk assessment and decision support for operation
- Principles of operational support using operational risk assessment functions
- Highlighting major technologies

The demonstrator is based on technologies for the remaining lifetime estimation and determination of the conditional view [1], the modelling of the operational risk using component failure and probabilistic cost information and MFOP models and technologies for decision support using multi-criteria decision-making, utility theory and simulation [2].

FIG 7 shows the demonstrator architecture based on the OSA-CBM standard and the integrated modules for condition view, operational risk assessment (divided in MFOP and ORA calculation) and the decision support module. As "managed" aircraft component an actuator simulation was used.

[8] The operational risk assessment approach was developed in close cooperation with HSU Hamburg, see also [5]

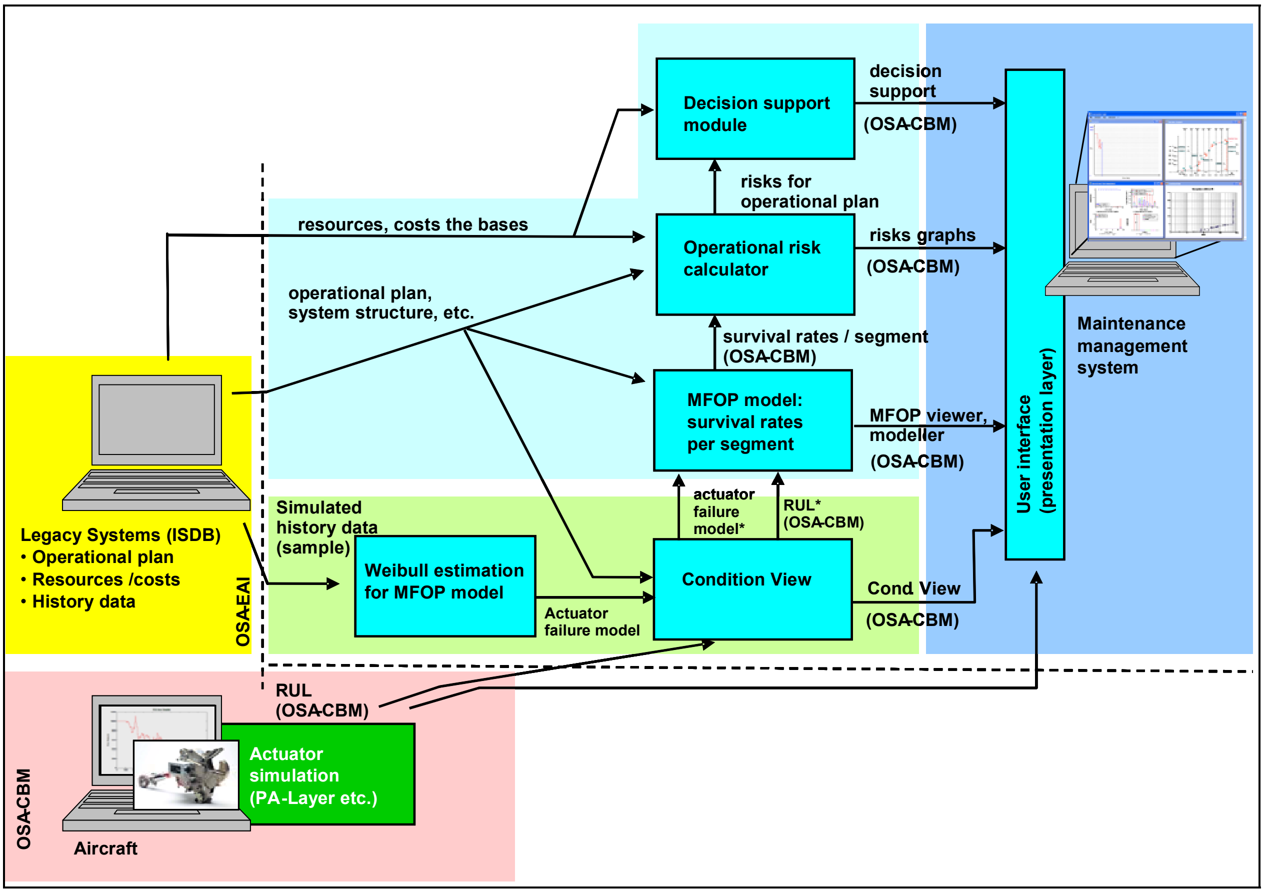


FIG 7. Operational risk demonstrator architecture [3]

4. ACKNOWLEDGEMENTS

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